

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

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In the Matter of:

THE INVESTIGATION OF THE USAIR
INC., FLIGHT 427,
A BOEING 737-300, N513AU : DOCKET NO. SA-510

ALIQUIPPA, PENNSYLVANIA,
SEPTEMBER 8, 1994

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Pittsburgh Hilton and Towers Hotel
Pittsburgh, Pennsylvania

Tuesday, January 24, 1995

The above-entitled matter came on for hearing
pursuant to notice, before JIM HALL, Chairman, at 8:35
a.m., before:

Board of Inquiry

Jim Hall, Member, NTSB
Chairman

William G. Laynor, Deputy Director,
Office of Aviation Safety

Ronald Schleede, Chief,
Major Investigations Division, Hearing Officer

Michael L. Marx, Chief,
Materials Laboratory Division

Office of Research and Engineering

John Clark, Chief, Vehicle Performance Division
Office of Research and Engineering

Technical Panel

Thomas E. Haueter, Investigator-in-Charge,
Hearing Officer

Gregory Phillips, Senior Systems Investigator

Charles Leonard, Operations Investigator

Thomas Jacky, Vehicle Performance Investigator

Cynthia Keegan, Structures Investigator

Roff Sasser, Systems Investigator

Staff:

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P R O C E E D I N G S

[Time noted: 8:35 a.m.]

CHAIRMAN HALL: I call the session back to order.

Before I call the first witness of the day, yesterday during our testimony, we had a witness, one of our investigators, discuss -- I'm sorry. The first witness who was a jump seat rider on Flight 1181, USAir Flight 1181 from Charlotte to Chicago, discussed what was an unusual noise that was reported during that flight.

We would request this morning if there are any other passengers that were on Flight 1181 from Charlotte to Chicago on September 8th, 1994 that have any other information that they think might be beneficial to this investigation, to please contact the National Transportation Safety Board at our offices in Washington, D.C.

They can contact Mr. Tom Haueter or myself, Mr. Jim Hall, if anyone was a passenger on that flight and would have any other information that they thought might be of benefit to this investigation in regard to

1 any unusual noises or information they might have on
2 the flight. This is the flight that preceded the
3 accident flight.

4 In addition, it was requested by several
5 individuals I spoke to last evening -- and I do not
6 know if we have any more -- do we have any more videos
7 this morning today, Mr. Haueter, that are going to be
8 shown?

9 MR. HAUETER: Maybe at the end of the day.

10 CHAIRMAN HALL: If we do have any more video,
11 that we ask the hotel people if they can assist us by
12 dimming the lights so that the videos can be seen as
13 clearly as possible by the individuals in the room.

14 With that, we will begin by calling our next
15 witness, Mr. David Rusho, a Boeing 737 Flight Control
16 Specialist with the Boeing Commercial Airplane Group in
17 Seattle, Washington.

18 (Witness testimony continues on the next
19 page.)

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1 MR. DAVID RUSHO, B-737 FLIGHT CONTROL SPECIALIST,
2 BOEING COMMERCIAL AIRPLANE GROUP,
3 SEATTLE, WASHINGTON
4

5 (Whereupon,

6 DAVID RUSHO,
7 was called as a witness by and on behalf of NTSB, and,
8 after having been duly sworn, was examined and
9 testified on his oath as follows:)

10 CHAIRMAN HALL: Mr. Schleede, if you will
11 proceed.

12 MR. SCHLEEDE: Mr. Rusho, give us your full
13 name and business address for our record, please?

14 THE WITNESS: Yes. My name is David Edward
15 Rusho and my business address is the Boeing Commercial
16 Airplane Group in Seattle, Washington, Post Office Box
17 3707 98124.

18 MR. SCHLEEDE: And what is your position at
19 Boeing.

20 THE WITNESS: My position is a lead engineer
21 and post-production engineer, which is, airplanes no
22 longer being produced in the production line at Boeing,

1 so basically the airplane I work on are the 707, the
2 727 and 737-100 and -200.

3 In that capacity, I'm lead engineer for
4 flight controls of those airplanes.

5 MR. SCHLEEDE: Can you give us a brief
6 synopsis of your background and education that
7 qualifies you for your present position?

8 THE WITNESS: I have a bachelor of science in
9 mechanical engineering from Washington State University
10 in 1958 and a P.E. license in mechanical engineering
11 for the State of Washington in 1976. I have 37 years
12 with Boeing; five years instructional tests working on
13 the 737 and 707. I have 24 years in project design,
14 primarily in flight controls, mechanical design, where
15 I've worked on the 707, 727, 737, 757 and 767.

16 The past eight years I've been working in
17 post-production engineering.

18 MR. SCHLEEDE: All right. Are you a
19 designated engineering representative?

20 THE WITNESS: No, I'm not.

21 MR. SCHLEEDE: Okay. Thank you.

22 Ms. Keegan will proceed.

1 MS. KEEGAN: Good morning, Mr. Rusho.

2 THE WITNESS: Good morning, Ms. Keegan.

3 MS. KEEGAN: What was your role in this
4 investigation?

5 THE WITNESS: I was asked by our Boeing Air
6 Safety Group to participate in this investigation to
7 look at cables. And I was under the direction of Mr.
8 Keegan and the NTSB.

9 MS. KEEGAN: Why was it important for you to
10 look at the cables? What was the purpose of you
11 looking at the cables?

12 THE WITNESS: The purpose of the cables,
13 primarily, to see if there's any preexisting cable
14 failures prior to the incident which -- you know,
15 preexisting, if cables had been broken prior to the
16 incident. And also, we hope to gather information to
17 possibly determine positions of the surfaces that these
18 cables control.

19 MS. KEEGAN: Okay. First of all, could you
20 describe in detail how you went about identifying the
21 different cables and then how you went about locating
22 them and reconstructing them to their proper location?

1 THE WITNESS: Okay. The cables that I looked
2 at were the aileron bus, the spoiler and the rudder
3 cables. Now, to really understand these cables, we
4 should put the viewfoil up.

5 MS. KEEGAN: Is that Exhibit 7-J?

6 THE WITNESS: 7-J, page 7.

7 MS. KEEGAN: Dave, could you turn toward the
8 microphone when you speak?

9 THE WITNESS: Yes. Okay. I guess I can't
10 use this pointer.

11 CHAIRMAN HALL: I believe you can take that
12 microphone over it's holder.

13 THE WITNESS: Can you see that pointer?

14 MS. KEEGAN: No. Not from over here.

15 CHAIRMAN HALL: Mr. Purvis, do you have
16 another pointer?

17 MR. PURVIS: They're going to get it now.

18 CHAIRMAN HALL: Okay.

19 THE WITNESS: First of all, I'd like to say
20 that I participated in this investigation in four
21 phases and those four phases involved going to
22 Pittsburgh to look at these cables. In the first

1 phase, I was told to look at the aileron bus and
2 spoiler cables. Now, if you look at the diagram up
3 there, you can see the aileron bus cables are the ones
4 that are called ABSB and ABSA on the left-hand and on
5 the right-hand. What these cables are, they come from
6 a power control unit located in the wheel well, and
7 they go out on the rear spar to the aileron and they
8 drive the left-hand aileron and the right-hand aileron.

9 And the reason we call those bus cables is
10 because they basically link the left-hand and right-
11 hand systems together, so they work in concert.

12 CHAIRMAN HALL: Sir, it would help us if you
13 would just -- if you would on each one of these,
14 although it may be elementary information to some, if
15 you'd tell us where the aileron is located on the
16 airplane and on each one of these where you're going to
17 be describing the cable and what's functioning.

18 THE WITNESS: Yes, sir. Okay.

19 The aileron is on the trailing edge of the
20 wing outboard of each wing. There's one aileron in
21 each wing. There's the right-hand aileron and there's
22 the left-hand aileron.

1 The bus cables come form the power control
2 unit in the wheel wells, and I'll point to it. That
3 says aileron power control units right in the middle of
4 the picture there, right there. That is controlled by
5 the pilot's control wheel through a cable system that
6 goes down the body. The cable system goes through the
7 body to the wheel well.

8 Okay. Here. I've got something here if I
9 can figure out how to use it.

10 Okay. Here we go.

11 So here is the control cables that go back to
12 the wheel well and drive the power control units, which
13 drive the aileron bus cables, which drive the aileron.

14 The reason we wanted to look at the aileron
15 bus cables is that is an important linkup between the
16 power control units and the ailerons and we wanted to
17 be sure that that linkup had integrity. So the first
18 thing we did was look to see if those aileron bus
19 cables had any preexisting failures.

20 We located them in the -- they were in the --
21 this wreckage was in a hangar at the Pittsburgh Airport
22 and we had the wings, the remains of the wings, left-

1 hand and right-hand wings. The rear spar were in place
2 and these aileron bus cables were attached to the
3 quadrants.

4 So we located these bus cables, identified
5 them, and then after we identified them and measured
6 them in place and looked at the fractured ends to see
7 if there was anything other than tensile overload, we
8 then took them out of the airplane and laid them out
9 and measured the length as exactly as we could. And
10 then we were able to reconstruct it, based on the
11 drawings, the relative position of these cables
12 relative to the airplane.

13 The spoiler cables similarly come from what
14 we call a spoiler mixer box. Now, there's a difference
15 in these cables. These cables here are 3/16, the bus
16 cables, the largest cables and only large cables in the
17 airplane. The spoiler cables are 3/32.

18 Now, in this diagram it looks like there's
19 only one cable out here, but this is just for the
20 demonstration. There's actually one spoiler cable for
21 each spoiler. The spoilers are on top of the wing and
22 these are flight spoilers. These only drive the flight

1 spoilers. There's two flight spoilers on the left-hand
2 wing and two flight spoilers on the right-hand
3 wing. And each -- one cable set drives each
4 spoiler.

5 And from the mixer, each one, the left-hand
6 goes out to the left from the mixers. The right-hand
7 goes out to the right from the mixer also. And this
8 again, comes from an input from the aileron control
9 wheels.

10 In addition, we have a speed brake input to
11 the mixer, so we can use these as speed brakes in the
12 air. Again, the importance of this spoiler -- finding
13 the spoiler cable is to determine if there was any
14 precondition failure because if they would fail, you
15 would have the spoilers pop up slightly. And part of
16 our exercise here and our investigation was to
17 determine what these cables condition was.

18 We were able to find a very small amount of
19 the cables attached to the spoilers and they were --
20 the center portions were all gone. We weren't able to
21 find any of the spoilers.

22 But on the aileron bus cables, we were able

1 to find practically all of them, even some of the
2 shorter sections in the wheel well.

3 When I went to Pittsburgh the first time, I
4 took a metallurgist along, a Boeing metallurgist. And
5 what he did, he looked at all of the broken ends of all
6 the cables that we could find in this aileron bus and
7 the spoilers, as well as a whole bunch of cables that
8 were -- of all the cables that were in the hangar. He
9 never found anything other than tensile overload
10 fractures on these cables. And we sent some of these
11 back to the NTSB that we had elsewhere. They also
12 looked at those.

13 So that was the way we reconstructed the
14 aileron bus and spoiler cables.

15 Now the rudder cables was a different story.

16 Oh, I might add that to do this I took a
17 second trip to go back and reconstruct the aileron bus
18 cables. And on the third trip I went back to
19 reconstruct the rudder cables.

20 Can you put up that other viewfoil there?

21 (Pause.)

22 Here's a rudder cable system.

1 CHAIRMAN HALL: What page number, please?

2 THE WITNESS: I think it's 6.

3 MS. KEEGAN: That's correct. That's page 6.

4 CHAIRMAN HALL: Page 6 in Exhibit 7-J is what
5 we have on the screen now.

6 Please proceed.

7 THE WITNESS: Okay. The rudder panels in the
8 cockpit have push rods going back to quadrants, two
9 quadrants, and each of these quadrants have a cable
10 attached to it that go the entire length of the
11 airplane up to the vertical fin to the aft quadrant
12 that drives the PCU. And attached to that aft quadrant
13 is a centering unit.

14 The length of these cables is 1100 inches and
15 these are 1/8 diameter cables. Back here at the back
16 end we have two turn buckles on each cable. The
17 problem with reconstructing these was that at the
18 hangar, we had a whole series of cables in boxes. What
19 we did, we took all the cables out of the boxes. We
20 separated the cables by diameter. Since we knew we
21 were looking for 1/8 diameter cables, we separated all
22 the 1/8 diameter from the 3/32 diameter cables and in

1 addition, then when we got those, we separated these
2 cables into longer lengths and shorter lengths.

3 We further separated them to have cables that
4 had turn buckles on them and we could eliminate any
5 cable that had a turn buckle that was not consistent
6 with the rudders. These turn buckles have part numbers
7 on them and we were able to find the four turn buckles
8 that relate to the rudder by finding these part
9 numbers, and then we could eliminate the rest of them.

10 Then we had a bunch of structures on some of
11 these cables. We further eliminated some of the 1/8
12 diameter cables that had structures on them, and in
13 doing so we were able to find three cable that ran
14 through the body that were associated with the rudder.

15 We had two cables, called the RA on this
16 side, and we found one called the RB on this side.

17 CHAIRMAN HALL: Dave, could I ask you just a
18 couple of very simple questions? Could you show us
19 exactly where the peddles are that the pilot and co-
20 pilot would push on that drawing?

21 THE WITNESS: Here are the -- the pilot's
22 peddle is right here and here are the co-pilot's

1 peddles.

2 CHAIRMAN HALL: Okay. And when the cable
3 runs back through the length of the plane, is it
4 running through the floor of the plane? What is it
5 actually running through?

6 THE WITNESS: This cable runs on the right
7 side of the centerline of the airplane, 4.5 inches to
8 the right. This one runs 4.5 inches to the left. They
9 go through the pressure bulkhead and as soon as they go
10 through the pressure bulkhead they go up to the
11 vertical fin.

12 CHAIRMAN HALL: Thank you.

13 THE WITNESS: An additional thing we looked
14 for was structure. We found an upper pulley on the RB
15 system that had a -- the cable was pinched on to that,
16 so we were able to identify that one. And then we were
17 able to identify two little sections that attached and
18 were broken off the aft quadrant and were able to match
19 those with the aft quadrant. So we were able to get
20 quite a bit of structure of cables back in here and get
21 a pretty reasonable idea of I think what that cable
22 situation was.

1 So that's basically how we reconstructed
2 these.

3 MS. KEEGAN: Okay.

4 THE WITNESS: I might add that a metallurgist
5 looked at all these cables with a 10x magnifying scope,
6 the fractured ends.

7 MS. KEEGAN: Describe the purpose of looking
8 at the cables with a magnifying glass?

9 THE WITNESS: What we were trying to do is we
10 were trying to find out if these fractured ends were
11 due to fatigue, due to tensile overload, due to wear or
12 due to corrosion.

13 MS. KEEGAN: Your viewgraph, page 5 of this
14 exhibit, I'd like you to get into some detail about
15 what you examined and what your findings were as far as
16 when you located the cables and how exactly you located
17 the cables and at what station locations you located
18 them.

19 THE WITNESS: Okay. This is a reconstruction
20 of our rudder cables based on measured lengths. Oh,
21 yes. We measured all the length of these cables.
22 Tried to measure them as accurately as we could in the

1 hangar area.

2 What this is is a reconstruction, a
3 calculation of a reconstruction of these cables. This
4 section here is based on the rudder being at a neutral
5 position.

6 CHAIRMAN HALL: Dave, again, are we looking
7 at the airplane? Could you give us a feel of how this
8 is laid out?

9 THE WITNESS: Okay. This is the aft quadrant
10 up in the vertical fin at the back end of the airplane
11 and the pressure bulkhead -- see where it says here aft
12 pressure bulkhead? So that's the back end of the
13 airplane.

14 These straight sections, straight cables, go
15 right through the body, all the way to the front of the
16 airplane.

17 CHAIRMAN HALL: So we're not looking at the
18 whole airplane. We're just looking at the -

19 THE WITNESS: No. We're looking -- well, we
20 are looking at kind of a shortened version of the
21 airplane, but this only shows the cables that we got,
22 that we were able to find.

1 So if you look at the reconstruction of these
2 based on this, these two ends here did not match.

3 MS. KEEGAN: Dave, could I just stop you for
4 just a second here?

5 THE WITNESS: Yes.

6 MS. KEEGAN: Station 420, I see it, the
7 forward end. Whereabouts on the aircraft is station
8 420?

9 THE WITNESS: Well, that's in front of the
10 wing towards the front of the airplane. This station
11 here is aft of the wing towards the back of the
12 airplane. This is right over the wing box area here.

13 So we don't really have any cables up front
14 other than this small section here. This is the
15 furthest one we had up front.

16 MS. KEEGAN: When you say we didn't really
17 have them, are you saying that you didn't find them or
18 that it was difficult to identify their proper
19 location? Would you be a little more exact with that?

20 THE WITNESS: We couldn't really identify
21 them. All those 1/8 diameter cables look alike and
22 they're broken up into various lengths. The only way

1 we could identify them is locating them through
2 structure.

3 These were free in structure here. This one
4 was pinched here but we were able to -- that's was the
5 only way we could identify them.

6 MS. KEEGAN: Now when you say it's pinched,
7 do you -- how did you come to the conclusion that it
8 was pinched and how could you determine whether it was
9 a result of the impact from the crash or that --
10 whether it had become pinched prior to the impact?

11 THE WITNESS: Well, it's consistent with the
12 destruction of the airplane and it was -- the idler,
13 the bracket holding the idler was just crushed into the
14 rub, and the rub was all broken up.

15 MS. KEEGAN: Dave, what do you mean by
16 pinched?

17 THE WITNESS: Pinched means that it was hard
18 to move. You couldn't pull it through there.

19 MS. KEEGAN: And as far as locating the cable
20 at this pinched idler pulley at Station 767, how far
21 back then were you able to locate the cable and how did
22 you know that the cable in fact went in the direction

1 aft instead of forward?

2 THE WITNESS: Well, we know that the idler
3 pulley is on the rear side of the floor beam and then
4 we're able -- then measuring this, we're able to
5 determine what the aft most position of the broken end
6 of this cable was. When we found that out, we found
7 that there's a 21 inch overlap between this cable that
8 comes from the aft quadrant to the horizontal floor
9 beam cable. But we confirmed that these two cables
10 matched, so we were convinced that this was a match.

11 MS. KEEGAN: How do you account for the
12 overlap?

13 THE WITNESS: Well, we think what happens is
14 this cable is under tension during the accident and
15 what happened, it broke and then pulled back and then
16 pinched at this point.

17 One of the pieces of evidence that we have is
18 at station 767-C, which is 20 inches forward of this
19 station here, there is a -- going through the hole on
20 RA, there was a notch the same diameter as the cable.
21 We think at that point is where the cable broke bending
22 over that hole and then it broke at that point and then

1 pulled aft about approximately 20 inches and then ended
2 up in this position with the collapse of all the
3 structure here.

4 MS. KEEGAN: Dave, I'd just like to make
5 sure. Are we talking about the right or the left
6 cable?

7 THE WITNESS: This cable drives the -- it's
8 the right -- it's on the right-hand side on the bottom
9 but it drive the rudder left.

10 MS. KEEGAN: Okay. You mentioned a notch.
11 Could you please describe what your examination of a
12 notch revealed and how you came to a conclusion of
13 whether it was a pre-impact type of a condition or
14 post-impact?

15 THE WITNESS: Whether the notch was pre-
16 impact? Well, I don't know if I can really do that.
17 All I can say is this consisted of the failure mode I
18 described.

19 MS. KEEGAN: Could you give me a little more
20 detail about the failure mode you described just once
21 more?

22 THE WITNESS: Well, the failure mode would be

1 that if the cable broke at station 727-C, that's where
2 the notch was. That's where the cable is bent around
3 the hole. And because of that high loads, it broke at
4 that point and then pulled back. And that would be --
5 if it was at 727-C, that would be 6 degrees right
6 rudder.

7 MS. KEEGAN: The cable that runs all the way
8 -- your right cable then that runs all the way to the
9 rudder PCU, can you just go through and describe your
10 findings aft of the galley area and what you found as
11 far as any indications that you found that the cable
12 had integrity prior to impact?

13 THE WITNESS: Well, yes. The evidence points
14 towards the cable having integrity or not having any
15 preexisting failure, primarily because there was
16 multiple fractures at the back end, in the back
17 pressure bulkhead. There was also noticeable fractures
18 along the body cable run and we didn't find anything
19 other than tensile overloads on any of the cables. So
20 the evidence strongly points towards that the cable was
21 intact at the time of the incident.

22 MS. KEEGAN: Could you please five your

1 opinion as far as the examination of other control,
2 flight control areas such as pulleys, fair leads? What
3 did you examine and what were your findings?

4 THE WITNESS: Well, we didn't really
5 specifically just go out and look at pulleys and fair
6 leads. We did have a pulley in the upper overhead on
7 the RB that had a pinched cable also. There was -- and
8 also, there was some -- the eyeball seals at the
9 pressure bulkhead, they had some indications of
10 notching on them.

11 MS. KEEGAN: You're -- I want to just make it
12 clear on how you identified the spoiler, aileron and
13 rudder cables individually and how you separated those
14 cables. Could you just go over that one more time?

15 THE WITNESS: The elevator cables?

16 MS. KEEGAN: The spoiler -- yes -- rudder and
17 the aileron cables. Could you describe how you
18 separated those and what you found in the hangar as far
19 as the condition of all the cables and the difficulty
20 or the --

21 THE WITNESS: Yeah. Okay. The spoiler
22 cables were -- the only spoiler cables we found were

1 intact on the rear spar attached to the quadrants at
2 the actuator locations, and they were -- we had one
3 long cable and the rest of them were like 4 or 5 feet
4 long.

5 We identified them by the positioning, their
6 positions on the quadrant. We were able to identify
7 which cable by their position on the quadrant.

8 The aileron bus cables, since they're the
9 3/16 diameter, they were much easier to identify and it
10 was on the -- as far as the rudder cable, the
11 identification was only by the attachment of floor beam
12 structure.

13 MS. KEEGAN: What was your goal in relocating
14 the cables through the floor beams and relocating them
15 to their proper location? What were you trying to find
16 out from locating these cables?

17 THE WITNESS: Well, there were several things
18 that we hoped to accomplish by doing this. One of them
19 was, of course, to determine if there was any
20 precondition or preexisting failure of the cable. The
21 other thing was to be able to locate the fracture
22 surfaces with structure and try to identify the

1 position of the cable so we could try to establish what
2 the rudder position was in.

3 Another possibility that we thought -- looked
4 early onto was there's an auxiliary fuel tank just
5 after the -- in the aft body area, and we wanted to see
6 if there was a possibility that that could have had
7 some kind of impact on the floor beams and possibly
8 displace the rudder cables.

9 MS. KEEGAN: And what were your findings?

10 THE WITNESS: We found no indication on the
11 auxiliary fuel tank that it had any displacement. And
12 the tank itself was looked at and they found no problem
13 with that.

14 MS. KEEGAN: What is the history of in-flight
15 failure binding or any type of problem with the rudder
16 cables on the Boeing 737?

17 THE WITNESS: On the Boeing 737 we have no
18 history of in-flight problems of the cable system.

19 MS. KEEGAN: And the same question for the
20 aileron cables. Do you have any history of in-flight
21 cable of the aileron cables on the Boeing 737?

22 THE WITNESS: Yes. We've had some failures

1 on the aileron. We had three failures that I know of
2 on the aileron body cables and five on the aileron bus
3 cables.

4 MS. KEEGAN: And what were the circumstances
5 surrounding those failures?

6 THE WITNESS: I don't know what the
7 circumstance on all of them were, but we did have an
8 aileron bus cable that was worn out and basically
9 failed after a high number of hours. It failed on
10 takeoff.

11 I believe we had another one that was also a
12 similar in-flight failure.

13 MS. KEEGAN: Did you exhibit any evidence of
14 the same type of problems on this on USAir Flight 427
15 wreckage cables?

16 THE WITNESS: WE looked hard for evidence of
17 any wear on these cables and they are pretty easy to
18 determine if you've got wear. You get wire breakage
19 around the pulleys and we found nothing that had
20 anything like that at all.

21 MS. KEEGAN: And did you see anything unusual
22 with your examination of the spoiler cables in the

1 wreckage?

2 THE WITNESS: The spoiler cables were all
3 tensile overload failures and we didn't see anything
4 that was unusual.

5 MS. KEEGAN: And what is the history of
6 spoiler cable problems with the Boeing 737?

7 THE WITNESS: To my knowledge, we've had 13
8 failures of the spoiler cables.

9 MS. KEEGAN: And what were the problems with
10 those failures? What was the cause of those failures?

11 THE WITNESS: They were corrosion and wear.
12 Usually corrosion on those cables.

13 MS. KEEGAN: Did you find any evidence of
14 corrosion or wear on the spoiler cables in the USAir
15 wreckage?

16 THE WITNESS: We didn't see any corrosion on
17 I don't think any of the cables. The cables were all
18 in very good shape.

19 MS. KEEGAN: Okay. Thank you very much, Mr.
20 Rusho. That concludes my questions at that time.

21 CHAIRMAN HALL: Any of the parties desire to
22 question the witness?

1 Boeing. Anyone else?

2 (No response.)

3 If not, who's doing the questioning?

4 Mr. McGrew?

5 Please proceed.

6 MR. MCGREW: Thank you, Mr. Chairman.

7 Mr. Rusho, with respect to the RA cable which
8 you found pinched, in the unlikely circumstances that
9 that was pinched in flight, what would be the effect on
10 the operation of the rudder?

11 THE WITNESS: In that case you would control
12 it with the ailerons.

13 MR. MCGREW: But would the rudder move?

14 THE WITNESS: No.

15 MR. MCGREW: Would it move to the right? If
16 that cable were pinched, could the rudder move to the
17 right?

18 THE WITNESS: No.

19 MR. MCGREW: So the rudder would be locked in
20 position?

21 THE WITNESS: It would be locked in position.

22 MR. MCGREW: Thank you.

1 In conclusion, then, did you say that your
2 investigation showed that all of the rudder cables were
3 intact prior to the impact? Is that your conclusion?

4 THE WITNESS: Yes. That's our conclusion.

5 MR. MCGREW: And so you found --

6 THE WITNESS: This is our -- our structural
7 people agreed on this also. It was the conclusion of
8 the group.

9 MR. MCGREW: So you found no evidence of any
10 preexisting failures in the rudder cable system?

11 THE WITNESS: No. No evidence at all.

12 MR. MCGREW: Okay. Thank you very much.

13 CHAIRMAN HALL: All right. No other
14 questions from the parties? We will proceed with Mr.
15 Marx.

16 MR. MARX: I just had a few clarifying
17 questions.

18 You mentioned that a metallurgist from Boeing
19 was on scene or at the hangar looking at the cables and
20 that he used a 10x power, a hand lens, to take a look
21 at these fractures. Would you clarify -- I understand
22 quite a few of these cable sections were sent to the

1 Materials Lab in Washington. Which other examinations
2 were done? Do you recall how many of these cables and
3 why you sent them to Washington?

4 CHAIRMAN HALL: That's our laboratory, right,
5 Mr. Marx, that you're referring to?

6 MR. MARX: Yes. That's correct. That's
7 correct.

8 THE WITNESS: Pardon me? What was that?

9 MR. MARX: Well, I just want to know for what
10 reason they were sent to Washington?

11 THE WITNESS: We sent, I think, four of them.
12 Meanwhile, -- these were the more -- the typical cables
13 were a little more controversial and our metallurgist
14 wanted confirmation that his reporting was correct.

15 MR. MARX: Okay. And the Materials Lab in
16 Washington examined these at much higher magnifications
17 than a 10x?

18 THE WITNESS: I believe so.

19 MR. MARX: Okay. Thank you.

20 CHAIRMAN HALL: Mr. Clark?

21 MR. CLARK: Mr. Rusho, would you describe
22 what you would expect to happen if a rudder cable did

1 break?

2 THE WITNESS: If a rudder cable broke, you
3 would get a displacement of the peddles and you would
4 have the centering unit be the focal point of the
5 rudder and you could control the airplane with the
6 rudder trim.

7 MR. CLARK: Would you also be able to control
8 the rudder in one direction with the one peddle?

9 THE WITNESS: Yes. You could -- you'd have
10 one cable that could still be put in tension and you
11 could position the rudder with that one cable.

12 MR. CLARK: I believe you referred to some
13 litmus marks on the cable that if they did occur at the
14 impact, at the crash, that they were in a position to
15 command a 6 degree airplane move with the right rudder?

16 THE WITNESS: Yes. That's based on that
17 notch at station 727-C bulkhead.

18 MR. CLARK: Were you involved in the
19 examination of the pogo?

20 THE WITNESS: No, I wasn't.

21 MR. CLARK: Over the course of your work,
22 have you attempted to -- or have identified or

1 attempted to identify any mechanism in which a band
2 could produce a slow moving rudder?

3 THE WITNESS: No, I haven't.

4 MR. CLARK: Are you aware of anybody at
5 Boeing that has attempted to do so?

6 THE WITNESS: No. I don't know anybody that
7 has.

8 MR. CLARK: I have no further questions.

9 CHAIRMAN HALL: Mr. Schleede?

10 MR. SCHLEEDE: Thank you.

11 When Ms. Keegan asked you about the different
12 in-flight failures, I believe you said no history of
13 in-flight failures of rudder cables?

14 THE WITNESS: Correct.

15 MR. SCHLEEDE: Is there any other history in
16 the 737? Are you're aware of any other kind of jams
17 caused by a falling object or interference or ice or
18 any other mechanical interferences that cause rudder
19 cable jams?

20 THE WITNESS: Well, I don't know. I'm not
21 aware of any. We haven't researched that.

22 MR. SCHLEEDE: Are the slats your area of

1 responsibility as far as flight controls?

2 THE WITNESS: No.

3 MR. SCHLEEDE: I want to have the staff
4 assist and bring up Exhibit 11-A-1. She'll place it
5 right on top to your left there. I believe we have
6 another witness to cover this, but I thought I'd ask
7 you before you leave.

8 This is the maintenance record, Group
9 Chairman's Report, Addendum 1, and it's reference
10 maintenance history of rudder PCU change on the
11 accident airplane January 21st, 1993.

12 I'm particularly interested in the second and
13 third paragraphs. In the second paragraph it mentions
14 that there's a work card generated on the main rudder
15 PCU, output rod with chaffing damage. So the damage
16 was cleaned up and inspected probably within minutes.

17 The next paragraph talks about another work
18 card describing the replacement of a damaged main bolt.

19 Before I ask a question, is this an area --
20 are these the type of things within your area of
21 responsibility as a Flight Control Specialist?

22 THE WITNESS: Well, it would be, but in this

1 accident I was only involved in the cables. My area of
2 responsibility is strictly the cables.

3 MR. SCHLEEDE: They're your normal
4 responsibilities in your job?

5 THE WITNESS: Well, possibly -- yes, it could
6 be that it applied to the 737-100 and 200 or the 300.
7 This was probably addressed by someone --

8 MR. SCHLEEDE: So you wouldn't be able to
9 answer any questions about --

10 THE WITNESS: No. I'm not familiar with
11 this.

12 MR. SCHLEEDE: I'm sorry. I didn't hear?

13 THE WITNESS: I'm not familiar with the whole
14 thing so I couldn't answer your questions.

15 MR. SCHLEEDE: Thank you.

16 CHAIRMAN HALL: Mr. Laynor?

17 (Pause.)

18 Well, we are in a temporary recess while the
19 Court Reporter restores her line feed.

20 (Whereupon, a recess was taken.)

21 CHAIRMAN HALL: This hearing is back in
22 session. The Court Reporter is ready to go. Is that

1 correct? And we will proceed then with questioning by
2 Mr. Laynor.

3 MR. LAYNOR: Mr. Rusho, I'd like to refer
4 you, again, to Exhibit 7-J, page 6.

5 And Jerome, if you could put that up.

6 In your testimony apparently some confusion
7 still exists regarding the 21 inch overlap at station
8 1049.5 in the lower right-hand corner of that exhibit.

9 Can you explain the significance of that
10 again, please?

11 THE WITNESS: Well, we think that it was
12 broken at station 727-C, where the notch was, and then
13 after it broke, the tension in the cable collapsed all
14 at once and it pulled back 20 inches and was pinched at
15 the station 727 by the idler pulley. And that counts
16 for the calculated differences in the length.

17 MR. LAYNOR: So, the -- let me see if I can
18 get it straight. In your opinion, the notch would
19 represent impact damage that would be consistent with
20 the rudder position at the time of impact and the
21 overload -- and the overlap -- I'm sorry -- represents
22 cable stretched due to tension?

1 THE WITNESS: No. It represents displacement
2 of the cable 20 inches. The cable moved back to
3 station 727-D was where we found it in reference to
4 station 767. There's a 20 inch difference between the
5 floor beams. So 60 inches forward at 767 is where the
6 cable was broke. But we think what it did is it
7 actually moved -- it was actually 80 inches forward at
8 the time of the fracture and then pulled back to the
9 position we found it in. And that accounts for the 20
10 inch overlap.

11 MR. LAYNOR: And if I go with the 80 inches
12 forward at station 767, what kind of rudder position
13 would that correspond to?

14 THE WITNESS: That would be 6 degrees right.

15 MR. LAYNOR: What kind of rudder position
16 would the 60 inches forward correspond to?

17 THE WITNESS: You only have 4-1/3 inches to
18 travel to get full throttle, so it wouldn't be
19 applicable to any position at all.

20 MR. LAYNOR: All right. And you may have
21 answered this already, but I wasn't sure. Were you
22 involved in the examination of the centering spring

1 mechanism and the trim actuator?

2 THE WITNESS: No, I wasn't. All I did was
3 the cables.

4 MR. LAYNOR: Okay. Thank you, sir. That's
5 all I have.

6 CHAIRMAN HALL: Just a few brief questions.
7 But first, I would appreciate if we could put up that
8 diagram of the plane. And I don't know what exhibit
9 that is.

10 Cindy, do you know or Tom know off hand?

11 There we go.

12 If you could identify for us -- I believe you
13 talked about the spoilers, the ailerons and the rudders
14 being driven by cables; correct?

15 THE WITNESS: Yes.

16 CHAIRMAN HALL: Now that we've got the full
17 airplane, if you could show me where those pieces are,
18 and I would appreciate it.

19 This is Exhibit 9-S, page 1.

20 THE WITNESS: The ailerons are these segments
21 on the trailing edge right here. The spoilers are --
22 the flight spoilers are these two on opposite sides.

1 Yes. These two right here, these are -- the two
2 outboard ones are ground spoilers and another inboard
3 one is a ground spoiler.

4 So if you look at the two spoilers that we're
5 looking at on the left-hand wing are flight spoilers
6 and here is the aileron.

7 CHAIRMAN HALL: Now, what activates the
8 cables in a situation of each one of those? Begin with
9 the rudder, if you would. In the cockpit or --

10 THE WITNESS: Okay. The rudder is activated
11 by the pilot's peddles and/or the co-pilot's peddles
12 and he drives the cable system back to the PCU in the
13 fin, vertical fin. The ailerons are driven by the
14 control wheel bringing cables back to the power control
15 unit in the wheel well. That wheel well, the power
16 control unit then drives the aileron bus cable. That
17 is the output of the power control unit.

18 The output of the spoilers are driven
19 basically through the aileron control wheel. It then
20 goes through the meter box and the cable drives
21 actuators at the spoiler, at the flight spoiler
22 positions.

1 CHAIRMAN HALL: How many feet of cable are we
2 talking about?

3 THE WITNESS: There's 1100 inches of cable
4 for the rudder; approximately 422 inches of each
5 aileron bus; and approximately 260 inches for the
6 spoiler cables, left spoiler and right spoiler.

7 CHAIRMAN HALL: So you have a lot of cable to
8 sort through in the hangar.

9 THE WITNESS: Yes, we did.

10 CHAIRMAN HALL: Now is that color coded? How
11 do you tell the spoiler cables from rudder cable? Has
12 it got different colors on it? Does it not look alike?
13 Is it different size? How would you tell the
14 difference?

15 THE WITNESS: The cables are separated by 1/8
16 diameter cables. The aileron, through the body, the
17 elevator, the stabilizer trim, the flap controls, speed
18 brake, are all 1/8 diameter cables. The aileron bus
19 are 3/16 diameter cables. The spoiler cables are 3/32,
20 as well as the brakes cables and the engine control
21 cables.

22 So, when you have a whole bunch of broken up

1 cable like that, it's very difficult to determine what
2 they are. In fact, that's a big problem. We couldn't
3 really determine all the cables. We had to rely
4 primarily on the structure that it was attached to or
5 the part numbers on the turn buckles. And some of the
6 part numbers on the turn buckles were burnished off.

7 CHAIRMAN HALL: Now how many individuals
8 assisted you in this task of trying to identify the
9 cables?

10 THE WITNESS: Probably throughout the stage
11 it's probably about a half a dozen people.

12 CHAIRMAN HALL: Now, you mentioned that your
13 responsibilities at Boeing primarily covers the older
14 aircraft that are not presently in production?

15 THE WITNESS: That's correct.

16 CHAIRMAN HALL: And I believe you said that
17 there can be cable failures from fatigue, tensile
18 overload, wear or corrosion?

19 THE WITNESS: Right.

20 CHAIRMAN HALL: What is the lifespan of a
21 cable?

22 THE WITNESS: Well, I don't think there's any

1 rule of thumb on the lifespan other than it depends a
2 lot on the maintenance of the cables. And we recommend
3 you replace them when you get to a certain wear
4 condition, which we have defined in the maintenance
5 manuals.

6 CHAIRMAN HALL: And the maintenance manuals
7 are basically approved by the -- under federal
8 regulation for that airplane or is that just a
9 manufacturer's --

10 THE WITNESS: That's Boeing's recommendation
11 for the maintenance manual.

12 CHAIRMAN HALL: So there's not a specific
13 lifespan, but generally as an aircraft gets older that
14 there is a possibility that those cables may be
15 replaced as they become worn through fatigue, wear or
16 corrosion?

17 THE WITNESS: Yes. But I might point out
18 that fatigue is really not problem in our design.
19 Where we get into fatigue problem is due to misrouting
20 of the cables over keeper pins on the pulleys. That's
21 the only place I've ever seen fatigue on a cable.

22 CHAIRMAN HALL: Okay.

1 THE WITNESS: So, -- but we look for that.
2 That's one we looked for just to be sure.

3 CHAIRMAN HALL: All right. Well, I
4 appreciate the time that you and your colleagues have
5 spent in going through the cables and reconstructing
6 them to the best of the ability with -- given the
7 condition of the wreckage and appreciate your testimony
8 this morning.

9 You're excused, sir.

10 THE WITNESS: Thank you.

11 (Witness excused.)

12 CHAIRMAN HALL: The next witness is Mr.
13 Lester Berven. I hope that is the correct
14 pronunciation. If not, I will ask him to provide that.

15 He is a flight test pilot with the Federal
16 Aviation Administration in Seattle, Washington.

17 (Witness testimony continues on the next
18 page. |

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1 LESTER BERVEN, FLIGHT TEST PILOT, FEDERAL AVIATION
2 ADMINISTRATION, SEATTLE, WASHINGTON

3

4 (Whereupon,

5

LESTER BERVEN,

6 was called as a witness by and on behalf of NTSB and,

7 after having been duly sworn, was examined and

8 testified on his oath as follows:)

9

CHAIRMAN HALL: Mr. Schleede, if you would

10 proceed.

11

MR. SCHLEEDE: Yes.

12

Mr. Berven, would you state your full name

13

and business address for our record?

14

THE WITNESS: My name is Lester Berven. I

15

work in the Renton Office --

16

MR. SCHLEEDE: Get closer.

17

THE WITNESS: Is it on?

18

CHAIRMAN HALL: Is the witness' microphone

19

working?

20

MR. SCHLEEDE: Try it again.

21

THE WITNESS: There we go.

22

MR. SCHLEEDE: Seems to be now.

1 CHAIRMAN HALL: Just have to speak closely
2 into it, please, sir.

3 THE WITNESS: My name is Lester Berven. I
4 work as the -- in the FAA Office in Renton, 1601 South
5 Lind Avenue.

6 MR. SCHLEEDE: What is your position with the
7 FAA?

8 THE WITNESS: I'm the senior flight test
9 pilot for the FAA's Northwest Mountain Region, which
10 includes the Boeing Company.

11 MR. SCHLEEDE: How long have you worked for
12 the FAA?

13 THE WITNESS: Worked for the FAA since 1976.

14 MR. SCHLEEDE: Give us a brief description of
15 your education and background how that qualifies you
16 for your present position?

17 THE WITNESS: Certainly. I have a bachelor
18 of science degree in aeronautical engineering with some
19 post-graduate studies in aerodynamics and aircraft
20 systems safety. I have an airline transport pilot
21 rating. I'm rated in -- I have type rating in all the
22 Boeing airplanes except for the 707.

1 I worked for eight years at Edwards Air Force
2 Base in Flight Test and five years in industry as a
3 test pilot and I've worked for the FM since 1976 as a
4 certification test pilot.

5 MR. SCHLEEDE: You do have type rating in the
6 737?

7 THE WITNESS: Yes, I do.

8 MR. SCHLEEDE: And approximately how much
9 flight time do you have in total time and time in the
10 737?

11 THE WITNESS: My total flight time is
12 somewhat over 7,000 hours and I believe I have about
13 400-500 hours of flight test experience in the 737
14 series.

15 MR. SCHLEEDE: Thank you.

16 Mr. Jacky will proceed.

17 MR. JACKY: Thank you.

18 Good morning, Mr. Berven.

19 THE WITNESS: Good morning.

20 MR. JACKY: Could you briefly describe the
21 responsibilities of an FM flight test pilot?

22 THE WITNESS: Certainly. When an applicant

1 such as Boeing builds a new airplane and takes it out
2 in flight test themselves and develops it to the point
3 where they think it's a good machine, they submit it
4 basically to the FM. And as part of that process, we
5 go out and determine compliance with airworthiness
6 rules of Part 25.

7 It consists of performance and flying
8 qualities and systems evaluations.

9 MR. JACKY: Could you describe what is Part
10 25, please?

11 THE WITNESS: Part 25 is part of the Code of
12 Federal Regulations which specify the airworthiness
13 standards for transport airplanes.

14 MR. JACKY: And could you describe your
15 experience in FM certification flight tests, please?

16 THE WITNESS: Well, our office basically
17 covers all types of different airplanes. I've worked
18 in the transport airplane field in both the small
19 business jet transports and all the way up through the
20 large airplanes, also.

21 I've participated in essentially all of the
22 Boeing certification flight testing since about 1978,

1 and so that would consist of 727 modifications and
2 approvals and 737, 757-67, the 474-400 and currently
3 the triple 7.

4 We do modification testing on other business
5 jets like Lear Jets and Falcon Jets and small aircraft,
6 also.

7 MR. JACKY: And with the 737 aircraft, were
8 you involved in the certification of the 300 series?

9 THE WITNESS: I was. Yes.

10 MR. JACKY: And any of the other of the
11 series of the 37?

12 THE WITNESS: I've also done some testing on
13 the 737-200. I wasn't working at the FM in Seattle at
14 the time of its original certification, but some of the
15 follow on modifications for autopilot testing and some
16 engine modifications and also some after-market stuff
17 for a noise suppression on an applicant other than
18 Boeing.

19 MR. JACKY: As part of the FM's
20 certification of an aircraft, can you describe what
21 sort of flight tests would be accomplished on that
22 airplane?

1 THE WITNESS: Certainly. Once the aircraft
2 is developed to the point where it's structurally safe
3 and the ground structures tests and flutter tests and
4 Boeing has basically conducted a minimum set of
5 airworthiness performance and flying qualities test so
6 that the aircraft is basically safe for flight testing,
7 the FM issues --

8 CHAIRMAN HALL: A flutter test? What is a
9 flutter test?

10 THE WITNESS: Oh, an aircraft is not a fixed
11 solid body but it is flexible. And as you take the
12 airplane to higher and higher speeds at certain weights
13 you can get into modes where the aircraft starts to
14 vibrate uncontrollably and that's called flutter. And
15 so what we want to make sure is that the airplane
16 doesn't do that, and so that's what the flutter testing
17 is. They do ground testing to find out what the local
18 resonances for all the flight control systems and
19 interactions are, then they do it in flight testing,
20 also.

21 CHAIRMAN HALL: Thank you.

22 THE WITNESS: Okay.

1 We were talking about the process of flight
2 testing in a transport airplane. When the primary
3 safety tests have been completed and our structures and
4 systems and propulsion people and the FM aircraft
5 certification office are happy that the airplane is
6 ready for flight testing, they issue what we call a
7 type inspection authorization, which is kind of an
8 authorization for my group to go out and fly a
9 transport airplane and check its compliance with the
10 airworthiness rules.

11 And once that's issued, basically we work
12 together closely with the Boeing Company and we have a
13 very detailed test plan which shows when it's going to
14 be done, how it's going to be done and how many points
15 are going to be done. And we go out and we do all
16 these tests, which consist of takeoff and landing
17 performance and minimum engine out control speed and
18 stability and control and all different altitudes, and
19 stalls and stall characteristics, and also proof that
20 the systems and the avionics in the aircraft all
21 perform their intended function.

22 MR. JACKY: And as part of this

1 certification, do you perform any flight tests with
2 regard to the control surfaces of the airplane?

3 THE WITNESS: With regard to control
4 surfaces? Are you talking about augmented, like an
5 aileron -- I mean, an autopilot testing?

6 MR. JACKY: Yes, but specifically at this
7 point in regards to the primary controls, such as
8 aileron, elevator, rudder controls.

9 THE WITNESS: We test those from the
10 standpoint that we do stability control testing. That
11 is, we take the aircraft to its -- all it's approved --
12 it's maximum approved altitude and actually beyond its
13 maximum approved speeds to show that we have some
14 margins in the airplane. And for the lateral
15 directional case, for instance, that is the rudder and
16 the aileron, we do what we call steady heading slide
17 slopes where we stabilize at various speeds and then
18 put in -- opposing the rudder and aileron to maintain
19 the heading and track of the airplane and go all the
20 way to full deflection to see that the forces and
21 moments on the control system are linear and don't
22 reverse so it moves in a stable direction.

1 So in that case, we do do a control system
2 evaluations.

3 CHAIRMAN HALL: Excuse me, Mr. Jacky, just a
4 moment. Could you help us just by explaining a slide
5 slope for us?

6 THE WITNESS: Certainly. Basically, the
7 optimum way to fly an airplane is to point it directly
8 into the wind because it has the minimum profile drag
9 area when you look at it from the front. If you don't
10 do that, you pick up drag and also in some cases where
11 you get the excessive slide slip, some buffeting.

12 So the purpose of the stability, directional
13 stability of the airplane, is to keep the airplane
14 pointed straight ahead into the wind.

15 The pilot can change that and he normally has
16 to do that on a slide slip or for some type of
17 maneuvering. If he'd just push on the rudder and then
18 use opposite ailerons so that the airplane doesn't roll
19 and basically can set the airplane sideways to the wind
20 so that you're flying sideways like this.

21 And so, for instance, instead of the airflow
22 going directly into the front of the nose of the

1 airplane, it's coming in like a side window. That's a
2 side slip.

3 CHAIRMAN HALL: Thank you.

4 MR. JACKY: And as part of the certification
5 flight test, do you ever perform or look at control
6 surface hardovers or going to the full deflection at
7 all?

8 THE WITNESS: Not in the primary flight
9 control system, no. The presumption -- well, the
10 airplane is designed to have enough control power to
11 basically do whatever the pilot wants any time he wants
12 to do it. So, you have enough control power in the
13 elevators and the ailerons and in some cases in the
14 rudder to make the airplane do some rather unusual
15 maneuvers.

16 So, the presumption is that the flight
17 control system is basically, from the standpoint of
18 full deflections, it's just as safe as the primary
19 structure. So we don't presume and we don't test any
20 types of full deflection hardovers of any of the flight
21 control systems.

22 MR. JACKY: Okay. Thank you.

1 Could you explain your role or your
2 participation in this accident investigation?

3 THE WITNESS: I've only been formally on a
4 couple of accident investigations. One was on a Lear
5 Jet and I was just kind of attached to one of the
6 overrun accidents there at LaGuardia. I can't remember
7 the name of it. And I just kind of acted as a
8 consultant. I haven't done a lot of formal accident
9 investigation.

10 MR. JACKY: In terms of the accident of USAir
11 427, what was your participation?

12 THE WITNESS: I basically acted as a pilot
13 consultant to the performance group and I flew a couple
14 of the simulator sessions: one, to look at
15 controllability; and also to look at the vortex
16 interaction.

17 MR. JACKY: And would that be under the
18 Aircraft Performance Group?

19 THE WITNESS: Yes.

20 MR. JACKY: Prior to the simulator -- or, let
21 me ask you this.

22 Where were the tests performed that you

1 participated in?

2 THE WITNESS: The tests were performed in the
3 en-cab there at Boeing Company.

4 MR. JACKY: Is this the simulator that Mr.
5 Kerrigan spoke to yesterday?

6 THE WITNESS: Yes, it is.

7 MR. JACKY: Prior to that, did you have the
8 opportunity or did the FM have the opportunity to do
9 any simulator testing with Boeing?

10 THE WITNESS: Yes. We sort of did some on
11 our own initially right after the accident.

12 MR. JACKY: Could you characterize the events
13 leading up to that session?

14 THE WITNESS: Certainly. After the accident
15 occurred, we were quite aghast that this thing could
16 possibly happen because we've tested this airplane to
17 all kinds of strange and unusual maneuvers and well
18 beyond the limits of the air speed and stall
19 characteristics and autopilot and yaw damper hardovers
20 and found that there was really nothing wrong at all
21 with the airplane at all.

22 So, we were taking quite aback -- taken aback

1 that something like this could happen. So one of our
2 pilots in discussing what the heck could possibly cause
3 this sort of thing, had a chance to fly on a 737
4 simulator for another test. Basically it was the
5 development of a head-up display system. And during
6 that test, while he was in the en-cab simulator, it
7 turned out that the head-up display didn't work very
8 good and he had to sit there for 40 minutes for them to
9 fix it.

10 So, while he was there, he decided to play
11 around with flying qualities of the airplane and he did
12 some checks for rudder/aileron trades. That is,
13 statically. We're talking about straight ahead steady
14 heading slide slips. And discovered that -- pretty
15 much what Mr. Kerrigan said yesterday -- that at the
16 accident condition of flaps 1 and 190, that if you put
17 the aileron and rudder in very slowly, you're basically
18 balanced right there.

19 Full rudder and full wheel will just maintain
20 control of the airplane. If you go faster than that,
21 the ailerons have more control power and if you go
22 slower than that, the rudder has more control power.

1 But that's a normal characteristic and it's certainly
2 acceptable, and a lot of airplanes are like that, too.

3 He then decided to try some dynamic inputs
4 for the rudder to see if that could possibly be the
5 problem. So, stabilized at 190 and flaps 1, basically
6 with the autopilot turned on and stabilized in level
7 flight, he just basically pushed on the rudder all the
8 way to the stop. Took about 2-1/2 to 3 seconds to get
9 there. And he was quite surprised at the response of
10 the airplane. It rolled quite rapidly into the rudder
11 deflection. And as quick as he could react and
12 disconnect the autopilot, he was up to about 50 to 55
13 degrees.

14 And as he added back pressure to hold the
15 nose up and then fed in some left aileron to try to
16 stop the roll -- the airplane essentially rolled all
17 the way over to about 120 to 140 degrees. He didn't
18 continue the maneuver because he didn't want to crash
19 the simulator and mess up the head-up display test, but
20 he thought it was quite interesting and he did it a
21 couple of times.

22 And so he recovered from the maneuver and

1 then reported back to us that this might be an
2 interesting area to look into to see if this could be a
3 possible cause of the accident. So, we called the
4 Boeing Company and said, "As part of our continued
5 operational safety responsibility, we'd like to take a
6 look at the flying qualities and controllability of
7 this airplane and the dynamic rudder input, which we
8 hadn't done during the certification tests."

9 And they set up a four-hour session for us
10 and we wrote up a little test plan and basically went
11 into the simulator and did essentially what the
12 performance group mentioned a little later on. I might
13 add, with just the same results, too.

14 So we looked at several different things:
15 trim runaways and different rate, hardovers on the
16 rudder and the aileron rudder trades and stalls and
17 several other things.

18 MR. JACKY: Previously when you were
19 discussing the tradeoffs between the rudder and the
20 ailerons, you said that that was a normal
21 characteristic of the airplane. Is that correct?

22 THE WITNESS: That's correct.

1 MR. JACKY: Could you describe why that is a
2 normal characteristic, please?

3 THE WITNESS: Well, basically, what we're
4 looking for is in our airworthiness rules we want the
5 airplane to fly normally. That is, when a pilot gets
6 in a new airplane he wants to be able to transition and
7 use his previous experience. So there are some
8 characteristics that make up what a normal airplane
9 feels like, and one is the ability to roll the airplane
10 with the rudder, and the other one is that when you do
11 side slip the airplane intentionally, it requires
12 opposite ailerons to stabilize. That's basically an
13 airplane characteristic since day one, so we want them
14 to fly like that so it feels normal.

15 Now, how much aileron you use for a given
16 rudder is really a function of the different airplane
17 design and the size of the vertical fin and the length
18 of the fuselage and such like that. So basically, we
19 go out and define what that is and so we stabilize at
20 particular speeds and particular flaps headings and we
21 do these side slip tests and we make a plot of the
22 aileron versus rudder deflection to look to see that

1 it's not too steep, it's steep enough, and it doesn't
2 become non-linear at the end. And basically, that's a
3 test that you do for all airplanes.

4 That basically defines the lateral
5 directional stability of the airplane.

6 MR. JACKY: And it's your belief that all
7 transport category aircraft behave in this manner?

8 THE WITNESS: Yes. All transport category
9 airplanes roll due to rudder and in the correct
10 direction.

11 MR. JACKY: If I could refer your attention
12 to Exhibit 13-B, page number 4, what this is is a
13 listing of simulator failures or malfunction scenarios
14 attempted by the Aircraft Performance Group in the
15 Boeing en-cab simulator.

16 Were you present at the time that these tests
17 were performed?

18 THE WITNESS: Yes, I was. I flew about half
19 of them, by the way.

20 MR. JACKY: Okay. What I would like to do is
21 work my way down this list and ask you about what
22 basically each test is and how it's performed and what

1 were the results.

2 For example, Number 1. Could you please
3 explain the one engine cut at climb power, please?

4 THE WITNESS: Yes. Basically, what we're
5 looking there is that when you lose an engine on an
6 airplane, a couple of different things happen.

7 Number one, you lose the thrust of that
8 engine and you also build up a drag because now you're
9 blowing the engine around by the air like a pinwheel.
10 So you both lose thrust and increase the drag on that
11 side, which is essentially the same as putting rudder
12 in in that direction, and so you wind up in the same
13 kind of a side slip situation we talked about before.
14 So that if you cut the left engine, the nose goes left
15 and you're side slipping to the right, which makes the
16 airplane roll to the left.

17 And so we were looking at the characteristics
18 of how much will it roll when you cut the engine at
19 climb power. Is it a very rapid departure or can you
20 control it easily.

21 So basically, what we did, we set the
22 airplane up at 190 knots at climb power, which is

1 maximum continuous thrust, actually, at 190 knots and
2 flaps 1 and just shut the fuel off on the left engine.
3 And then we looked at the resulting reactions of the
4 airplane. And basically, it was not a significant
5 problem. If you don't put any control input at all, the
6 airplane only rolls about 11 degrees per second. It
7 completely controls free with no pilot input at all.

8 If you use a representative delay, which is
9 what we use for autopilot testing, which is pilot
10 reaction plus 3 seconds, in other words, the pilot
11 knows something happens. It gets it attention and then
12 we wait 3 seconds to give him time to react. The
13 airplane basically will roll only to 45 degrees in that
14 scenario with no pilot input. So it was rather a
15 benign maneuver.

16 MR. JACKY: In Number 2, we have several
17 rudder hardover rates, A through F. Could you please
18 describe what the practical application of each of
19 these rates would be? What type of rate or why would
20 you expect those types of rates in the airplane or what
21 could be the cause of those type of rates?

22 THE WITNESS: Well, the first rate --

1 CHAIRMAN HALL: Again, just before we get
2 into this, Mr. Jacky, if any one of you all could give
3 me -- when you say rudder hardover, what's hardover?
4 What are you referring to?

5 THE WITNESS: That comes from an autopilot
6 testing term. And basically, if you're letting a black
7 box fly the airplane, you want to be assured that
8 whatever it can do in its worst case is not going to
9 cause a maneuver the pilot can't recover from with a
10 reasonable delay. So the pilot, if the autopilot is
11 flying both a pitch and roll axis, for instance, we
12 take -- take, for example, the roll axis. We put
13 enough voltage on the servo of the autopilot to
14 saturate it. In other words, more than it needs to go
15 to full deflection.

16 So it goes full deflection as much as it can
17 as quick as it can and stays there. And so, hardover
18 means as far as the controls and as far a direction as
19 they'll go as quick as they can move. And that's
20 basically what we're talking about for a hardover.

21 CHAIRMAN HALL: Thank you.

22 THE WITNESS: The rudder hardover rates then,

1 basically these tests were done by allowing the rudder
2 to go to full deflection but at the rate shown. And
3 the intent of doing these as different failure rates
4 was to try to match or look at the departure rates
5 shown on the FDR to see if we could come up with
6 something that was similar that way.

7 Coincidentally, the first one, Number A, is
8 basically the same rudder hardover failure rate that
9 you would get with a trim runaway, a rudder trim
10 runaway, which is electric in this airplane. So the
11 initial reaction would be the same, although with a
12 trim runaway, which we also did, the rudder only goes
13 to 13 degrees instead of full over.

14 MR. JACKY: And why is that?

15 THE WITNESS: Because the rudder trim is
16 limited to a maximum authority of about a little more
17 than half deflection, because basically you don't need
18 any more rudder trim than that. To trim the engine, to
19 trim the -- I think the maximum rudder trim requirement
20 is with engine out, the engine out requirement at 1.4
21 times the stall speed. So basically, you don't make
22 the controls any more powerful than they need to be

1 because of the possibility of it running away like
2 that.

3 For example, on the aileron trim and on the
4 rudder trim, in flight tests if you can't disconnect an
5 autopilot or electronic augmentation system, we require
6 that it runs all the way to the stop and then we react
7 to it. So basically, for a rudder trim hardover, we're
8 running all the way to 14 degrees and for an aileron
9 trim runaway, we'll run it as far as it can go and then
10 it's sure that the pilot can make a continued safe
11 flight and landing without any problem.

12 So that's why it's limited to a certain
13 number of degrees. If it does run away, you don't want
14 it to cause a problem.

15 MR. JACKY: So in your flight certification
16 tests, you would be more apt to test the runaway rates
17 of the trims of the control surfaces as opposed to
18 testing for the full travel of the surface itself?

19 THE WITNESS: That's correct. Basically, we
20 know that there are failure rates in electronic
21 augmentation systems and autopilots. Based on our
22 experience we know that it's going to happen. So

1 basically, we want to assure ourselves that there are
2 no hazardous characteristics involved with an autopilot
3 hardover or any kind of electronic augmentation
4 hardover.

5 We discovered as we were doing this that the
6 maximum roll rate that was achieved as a function of
7 the rudder hardover rates was pretty much a one to one
8 relationship. In other words, if you put the rudder in
9 at a faster rate, the airplane rolled at a faster rate.
10 And we discovered that.

11 In truth, what was said before was true, that
12 if you do it very, very slowly and stabilize the
13 airplane in a straight ahead side slip, the rudder and
14 ailerons are exactly equal at 190 knots and flaps one.
15 However, if you put the rudder in at any rate, then
16 basically the rudder will roll the airplane faster than
17 the aileron will.

18 And so we discovered that the hardover rate
19 here, the maximum rate that you would achieve is pretty
20 much proportional to the rudder hardover rate. And the
21 data that we got from the Performance Group shows that
22 a half a second -- half a degree per second hardover

1 rate shows only about -- the airplane would roll 70
2 degrees in 17 seconds, which is pretty slow. It's an
3 average of about 4 degrees per second.

4 And you work your way up that way and then
5 you find out that at 2-1/2 degrees per second it rolls
6 75 degrees in 7-1/2 seconds, which is up to 10 already,
7 and it progresses all the way down pretty much linearly
8 until you get the maximum rate, which is just basically
9 to stomp the rudder all the way to the floor at 52
10 degrees per second. At that point, the rudder rolls
11 the airplane due to the dihedral effect we were talking
12 about at about a maximum rate of 32 degrees per second.

13 There's some additional data later on, too,
14 that shows the aileron only, but basically what we're
15 looking here at the rudder hardover rates and the roll
16 rate of the airplane and the reaction of the airplane
17 based on those.

18 MR. JACKY: Was I correct? You just said you
19 discovered something regarding the rudder roll rate?

20 THE WITNESS: The roll rate of the airplane
21 due to the rudder, yes. In other words, we talked
22 about -- yesterday, Mr. Kerrigan explained what the

1 roll due to the side slip was caused by. And if you
2 have a swept wing airplane with the wings like this, if
3 you yaw the airplane like this, the wing on the right,
4 for instance, if you're yawing nose left, the wing here
5 is more perpendicular into the wind and the trailing
6 wing is farther back. So therefore, you have more lift
7 on this wing than you have on that one. And that's a
8 static characteristic. So that if you're just
9 stabilized there with just rudder and aileron holding
10 it, that's the characteristic you have.

11 There are two other factors, however,
12 involved in that. One is the side slip overshoot when
13 you're using a dynamic rudder input, and the second one
14 is the fact that you roll also due to yaw rate. In
15 other words, when the airplane is yawing like this, the
16 wing on the outside has a slightly higher velocity than
17 the one that's going back. So that causes a little bit
18 higher dynamic pressure and a little bit more roll.

19 Secondly, when you put the rudder in at a
20 high rate, the side slip that you get, you get kind of
21 an overshoot due to the momentum of the maneuver so
22 that your side slip goes way up higher and then it will

1 eventually stabilize that, and therefore, causes a
2 higher roll rate initially due to a dynamic input than
3 you would have if you just put it in slowly and held it
4 statically.

5 So that's when you get an increasing roll
6 rate due to the rudder input rate.

7 MR. JACKY: And you weren't aware of that
8 prior to these tests?

9 THE WITNESS: Yes. We were aware of that.
10 And all airplanes do the very same thing. It's nothing
11 that's particular to the Boeing 737. All other swept
12 wing airplanes do it, too.

13 MR. JACKY: So rather than discover, you're
14 basically verifying those --

15 THE WITNESS: Pardon?

16 MR. JACKY: Rather than discovering, you were
17 actually verifying those results?

18 THE WITNESS: Yes. Basically, we knew that
19 the characteristic existed. What we were trying to do
20 here now is quantify it; how much and what's the
21 relationship between the roll rate due to the rudder
22 and the roll rate due to the ailerons which could

1 oppose it.

2 MR. JACKY: In looking at the rudder hardover
3 rates listed there, A through F, you may have already
4 done so, but could you characterize any of the rates as
5 being what you would believe or in your experience
6 would be consistent with the FDR data shown off of
7 USAir 427?

8 THE WITNESS: It really wasn't possible to
9 match it exactly, but as far as I can remember, the 2-
10 1/2 degree per second was about the closest one, 2-1/2
11 to 3 degrees per second. Again, it didn't match it
12 exactly but it was closer than any others.

13 MR. JACKY: Let me rephrase that. In looking
14 at just the initial first five or six seconds of the
15 upset, which one of those rudder rates do you believe
16 might or in your experience would most closely match
17 the FDR data?

18 THE WITNESS: I'd say it was 2-1/2 degrees
19 per second.

20 MR. JACKY: Okay. Moving on, in looking at
21 test Number 3, could you please explain that test and -
22 -

1 THE WITNESS: Well, there was one other thing
2 we did here, too, that I forgot to talk about. It was
3 the maximum, the yaw damper input. That was a slightly
4 different test in that the yaw damper itself has very
5 much little or very much less authority than the basic
6 rudder does. The rudder in a static deflection will on
7 the ground deflect 26 degrees and in flight, at these
8 flight conditions, it will deflect approximately 19 to
9 20 because the air forces blow the rudder back and the
10 yaw damper in this case is only going to deflect about
11 30 degrees.

12 So the roll rate due to yaw damper output at
13 full deflection hardover is really quite benign. I
14 think the airplane only rolls about 15-16 degrees per
15 yaw damper hardover.

16 CHAIRMAN HALL: Again, -- you do such a good
17 job of explaining, sir. If you give us just an
18 elementary discussion of what the yaw damper does, I'd
19 appreciate it.

20 THE WITNESS: Okay. Basically, the vertical
21 fin on an airplane acts like the feathers on an arrow,
22 so that if you're flying along there and the pilot is

1 not making an input and a gust upsets the airplane
2 laterally or directionally, like this, there's a wind
3 blowing on the opposite side of the rudder that pushes
4 it back around into the -- straight into the wind. On
5 slow speed airplanes and straight wind airplanes, that
6 does a pretty good job. But when you get to a swept
7 wing airplane and high wing loadings and high altitudes
8 and mach numbers, the arrow, the feathers on the arrow
9 are not quite as effective and you have to get to a
10 bigger angle before it will blow it back.

11 And so what you wind up with is an airplane
12 that wanders back and forth like this, left and right,
13 getting to a big enough angle that it will blow the
14 rudder back and straighten out the airplane. That's
15 the Dutch roll mode we talked about because when it
16 does this little snaking motion, we're talking about
17 the roll due to yaw, it does a little bit of a roll,
18 too, and it's kind of out of phase by 90 degrees and it
19 kind of wanders back and forth like this. It's more of
20 a nuisance than anything else, but typically every
21 major large jet transport has a yaw damper which is a
22 very quick reaction, automatic electronic system, that

1 moves the rudder quickly and stops this without the
2 pilot having to do anything with it.

3 CHAIRMAN HALL: And that can be controlled by
4 the autopilot?

5 THE WITNESS: It's controlled by a separate
6 unit called a yaw damper.

7 CHAIRMAN HALL: Thank you.

8 MR. JACKY: Just a follow-up question. The
9 yaw damper is not part of the autopilot system in the
10 737-300 aircraft?

11 THE WITNESS: I believe it is separate. Yes.

12 MR. JACKY: If you could get or, please, if
13 we could return to Item Number 3 and describe that
14 test, please.

15 THE WITNESS: Basically what this was was
16 input the rudder hardover, full deflection; don't make
17 any pilot input until the airplane rolls to about 80
18 degrees and then pull the column back into the
19 stickshaker. This is kind of one of many scenarios we
20 looked at to see what the aircraft response would be to
21 this kind of maneuver and basically the data that I
22 looked at, this is one where we left the autopilot on

1 and didn't disconnect it. It was somewhat similar to
2 the FDR trace.

3 The airplane goes all the way over and rolls
4 more than 360 degrees and back up to another 100
5 degrees. So it doesn't represent the FDR trace but it
6 is a significant departure from control flight.

7 MR. JACKY: And Item Number 4?

8 THE WITNESS: Basically, I guess a general
9 comment I would have, that all of these other failures
10 were benign. The only one that was really significant
11 was the rudder input.

12 The leading edge asymmetry with or without
13 auto-slats -- in other words, we put the leading edges
14 out on one side and then sling all the way down to the
15 stall on the airplane and the airplane rolls off, of
16 course, to about 70-80 degrees, which is what you would
17 expect. But it was controllable, recoverable.

18 On the next one, we have an auto-slat misfire
19 at the stickshaker, and I think that was from flaps 5
20 where the auto-slat starts to work. And what does is
21 when you slow down, you get into or just beyond
22 stickshaker, the leading edge devices extend

1 automatically, called auto-slats. And so we failed one
2 of those and had one come out and one not come out.
3 And that again, was pretty minor maneuver. It only
4 rolls about 10 degrees.

5 Number 6 is basically the same as Number 3 up
6 there and does the same thing.

7 MR. JACKY: And Number 7, Mr. Kerrigan spoke
8 to yesterday.

9 THE WITNESS: Yes.

10 MR. JACKY: And I believe that Number 8 and
11 Number 10 are relatively the same?

12 THE WITNESS: Yes.

13 MR. JACKY: Could you discuss Number 10 then
14 please?

15 THE WITNESS: Okay. Did you say Number 9 or
16 Number 10?

17 MR. JACKY: I said Number 10.

18 THE WITNESS: Okay.

19 MR. JACKY: Just skip Number 8, basically.

20 THE WITNESS: Okay. On Number 10, what we
21 were looking there was the aileron rudder trades from a
22 dynamic input. We wanted to see what the maximum roll

1 rate was using just the lateral control system, just
2 the rudder system, and then how much roll you could get
3 with them both used together hardover as quick as they
4 could move and then what would happen if you used them
5 in opposition.

6 Basically, what you have on the wheel input
7 rate for the data we got in the Performance Group, if
8 you don't use any rudder at all and just slam the wheel
9 hardover as far as it will go and hold it there, the
10 maximum rate that you reach is about 23 degrees per
11 second, and that's normal for the 737. Because
12 basically when you do that without the rudder input,
13 the ailerons, in conjunction with the spoilers, wind up
14 with a slight adverse yaw. The nose doesn't turn into
15 the turn as quick as it would if you used coordinated
16 rudder, so you get a little bit of adverse and you
17 don't rolls quite as fast with ailerons only.

18 With all the other controls free with a
19 rudder input rate of full deflection as quick as you
20 could move, it rolled to a maximum rate of about 30 --
21 a little more than 30-32 degrees per second.

22 Now, the next one where we did combined wheel

1 and rudder hardovers in the same direction, in other
2 words, you slam it over full rudder deflection and full
3 aileron deflection into the turn into the same
4 direction, you got amazingly enough, pretty much the
5 sum of those two, which is about 55 degrees per second.

6 When we did the adverse inputs, in other
7 words, it was rudder to the left, wheel to the right,
8 full deflection over like that, the airplane initially
9 did roll into the rudder because of the large side slip
10 that you built up. It overpowers the ailerons at the
11 beginning of the maneuver, but once this initial side
12 slip has damped out due to the stability, you wind up
13 with a maximum rate of about 17 degrees per second.
14 And then once you reach a bank angle of 40 degrees, the
15 airplane stops rolling and the balance of forces are
16 such that you're out of the dynamic case and now back
17 into the static case and the rudder and ailerons are
18 balanced.

19 MR. JACKY: And finally, if you could
20 describe the test in Number 9, please?

21 THE WITNESS: This was one of just many tests
22 we looked at just to get a general picture of the

1 characteristics of the airplane in all the kind of
2 combinations and permutations we could come up with and
3 this is one of the -- a rudder input hardover with
4 limited lateral control. In other words, they turned
5 off the roll spoilers and you had ailerons only. And
6 as I recall, in this condition of about flaps 1 and
7 190, the ailerons and the spoilers are just about the
8 same effectiveness.

9 So if you turn off the roll spoilers, you
10 basically have half the lateral control power that you
11 had previously. So in this case, with the rudder
12 hardover to the left, the airplane basically rolls
13 considerably faster to the left than it would normally.
14 And the maneuver in this case was basically the same
15 thing we got before. It was the nose dropping and the
16 airplane rolling, but it rolled so fast that it
17 completed the roll and wound up with about 45 or 60
18 degrees nose down, continuing to roll.

19 MR. JACKY: Thank you.

20 I wanted to ask you a couple of questions
21 regarding some of the simulations of the wake vortex
22 modeling. Let me ask first of all, did you participate

1 in those simulator sessions?

2 THE WITNESS: Yes, I did. I flew quite a few
3 of those.

4 MR. JACKY: And what was your general
5 impression of the wake vortex as modeled by Boeing
6 engineers?

7 THE WITNESS: I thought it was quite a good
8 simulation. In my flight experience I've probably
9 encountered 10 or 15 of these things at all different
10 angles; straight across, straight up, in landing
11 configuration and whatever, including in the 737. And
12 I thought it was an excellent simulation. It felt just
13 like it would in the real airplane.

14 MR. JACKY: And how would that feel in a real
15 airplane?

16 THE WITNESS: Basically, it depends on the
17 angle you cross the vortex at and how strong it is, but
18 typically a large crossing angle, in other words,
19 perpendicular to the vortex stream, is basically a very
20 hard hit but not much G. Say 3/10 of a G. And
21 typically it's very, very sharp, so it's like somebody
22 hit the bottom of the airplane with a baseball bat.

1 It's a jolt. And you say, "Wow, what was that?"

2 The more you turn parallel to the vortex
3 stream, the more roll you get out of it, so that if you
4 slide into one parallel like this, basically if it's a
5 strong vortex and you're very close behind the
6 airplane, it typically will just take the airplane and
7 yaw and roll it quickly like that. zow. And you wind
8 up typically in a 737 no more than about a 30 degree
9 bank. It rolls very fast but not very long. And it
10 spits you out one side of the vortex and you wind up at
11 a maximum of about a 30 degree bank.

12 MR. JACKY: And could you characterize the
13 Boeing distributed lift model that they made for the
14 737?

15 THE WITNESS: I didn't look at particularly
16 the data itself, but the airplane in the simulator
17 certainly flew a lot like the 737. And again, I say
18 that the vortex interactions with the 737 felt just
19 like I've experienced it in flight,

20 MR. JACKY: Do you believe that the simulator
21 aircraft flew with the distributed lift model off
22 compared to the -- let me rephrase that.

1 The simulator aircraft with the distributed
2 lift model flown on -- or turned on, and with the
3 distributed lift model turned off, did you feel that
4 the reaction or the flying characteristics of the
5 airplane were similar?

6 THE WITNESS: I don't think you can tell the
7 difference unless you're doing something like a vortex
8 interaction. Normally, flying around, what they mean by
9 a non-distributed lift model is they just put the lift
10 on one wing at the aerodynamic center of the wing.
11 It's the correct lift and the correct rolling moment,
12 so it feels normal to the pilot.

13 What they're saying is that you have to use
14 the distributed lift model where you segment the lift
15 across the wing and then integrate it, because what you
16 have is you have the vortex interacting with only part
17 of the wing, not the whole wing.

18 So what they wanted to show was the
19 incremental increase in the roll rate as you moved into
20 the vortex. So you couldn't tell the difference
21 between a distributed lift model and a non-distributed
22 lift model if you weren't entering a vortex.

1 MR. JACKY: You had previously described the
2 yaw damper and the yaw damper operation in the 737-300.
3 As a pilot, can you notice yaw damper input during
4 flight, normal flight?

5 THE WITNESS: Not really. Once you turn the
6 yaw damper on, it basically just does its job and keeps
7 the airplane from fishtailing. It makes the airplane
8 fly straight like it's supposed to. It's a series yaw
9 damper, which means that when the yaw damper moves the
10 rudder, it doesn't move the pedals, so it's doing its
11 job, transparent to the pilot.

12 MR. JACKY: In your experience, would you
13 expect yaw damper input during the wake vortex
14 encounter?

15 THE WITNESS: Yes. And it would depend, I
16 guess, on how you entered the vortex. Typically, the
17 ones that we saw in the distributed lift model in the
18 vortex simulation, if you went straight in it from the
19 side, it was mostly roll and not much yaw. If you came
20 at it from the bottom where you hit the vertical fin
21 first, it did yaw.

22 And basically what the yaw damper does, it

1 has a rate gyro on the back and it senses rate and puts
2 in rudder to stop that rate motion. So if anything
3 pushes on the rudder, a lateral gust or a vortex
4 encounter and it starts to yaw the airplane at a yaw
5 rate, basically the yaw damper says -- put an opposite
6 rudder to stop that rate.

7 So, yes, if you were in a vortex and you
8 continued to yaw, the yaw damper would put in as much
9 authority as it had until it stopped the yaw rate or it
10 was full deflection.

11 MR. JACKY: I meant to ask you a question
12 about your wake vortex encounter experience. When you
13 -- or how would you know that you had experienced a
14 wake vortex?

15 THE WITNESS: It's pretty unmistakable.
16 Basically, it's nothing like you encounter in normal
17 flight. It basically feels like some giant hand
18 grabbed the airplane and just took it right away from
19 you and moved it one direction or another. It's a bit
20 disconcerting, but --

21 MR. JACKY: Can you characterize the length
22 of time of this episode in general?

1 THE WITNESS: In the ones I've seen, I've
2 never seen it last more than just a second or two, two
3 seconds at the most. The ones that we saw on the
4 distributed lift model and the vortex here were --
5 typically when you're out there flying around in the
6 real world you don't hit both vortexes. They come off
7 the wing and they go down and they split. So
8 typically, you're not going to see both of the
9 vortexes. You're only going to run into one of them
10 and it's going just quick roll you up and spit you out
11 the side or just give you a bump as you go across it.

12 On the distributed lift model and vortex
13 interaction tests that we did in the simulator, we had
14 it set up so that you would go through both of them to
15 look at the worst case. And basically, it was very
16 difficult, even though the vortexes are actually
17 visual. You had to be very careful to get right in the
18 middle of it or it would just spit you out the top,
19 bottom or out one side.

20 It takes two or three tries to even get into
21 it. And the one that we finally did that looked real
22 good is we went in the left side vortex. It rolls the

1 airplane like this to the right, back, to the right,
2 and you come out the other side. And even with the
3 autopilot on, it could control the airplane and the
4 bank didn't get more than about 25 degrees.

5 But the typical, I think it was 1500 feet
6 squared per second vortex which we thought was the most
7 representative.

8 CHAIRMAN HALL: Mr. Jacky, if I might just
9 ask a question here. On the 737, how much authority
10 does the yaw damper have?

11 THE WITNESS: Well, it controls three degrees
12 out of the 26, so it's not a very high authority
13 system.

14 MR. JACKY: Does the FM require pilots to go
15 through any sort of wake vortex encounter training?

16 THE WITNESS: Not that I know of. There are
17 some good write-ups in the Airman's Information Manual
18 and I'm sure that -- I can just presume that the
19 airlines have some information on that. But there's no
20 formal training that I know of.

21 I'm not sure exactly what you would do.
22 You'd have to just say stay out of it, because it

1 happens so quick there's nothing you can do about it
2 anyway. You're in and out of it in a second or two.
3 So the best thing is to keep yourself from getting into
4 one and there's some techniques that are recommended on
5 how to do that; Advisory Circulars and the Airman's
6 Information Manual.

7 MR. JACKY: Does the FM plan on asking
8 Boeing to perform any sort of flight tests in regards
9 to this accident?

10 THE WITNESS: Not at this time.

11 MR. JACKY: I have no further questions.

12 CHAIRMAN HALL: Thank you, Mr. Jacky.

13 Do any of the parties have questions?

14 I only see a hand from the Airline Pilot's
15 Association. Anyone else?

16 (No response.)

17 If not, Captain, your question, please.

18 CAPTAIN LeGROW: Thank you, Mr. Chairman.

19 Good morning, Mr. Berven.

20 THE WITNESS: Hi.

21 CAPTAIN LeGROW: I have just a couple of
22 questions.

1 First of all, when the FM does a
2 certification or did the certification on the 737-300,
3 did they do a new aircraft certification test?

4 THE WITNESS: Basically, yes. There were
5 enough changes in the airplane. The lengthening of the
6 fuselage and the different engines, the different
7 material in the elevators and different cockpit,
8 different instrumentation, that basically -- the stuff
9 that I'm involved in is called Subpart B, which is
10 performance and flying qualities, and we did every one
11 of those all over again. And the systems tests that
12 were changed were basically -- most all of them, we did
13 those also.

14 So it was essentially a new certification
15 program.

16 CAPTAIN LeGROW: So it wasn't grandfathered
17 in in the previous models. It had a full new aircraft
18 certification?

19 THE WITNESS: Yes, it did.

20 CAPTAIN LeGROW: Thank you.

21 THE WITNESS: I believe the original
22 certification basis was still used, but we did the test

1 that we would do on basically a new airplane.

2 CAPTAIN LeGROW: Thank you.

3 On the wake vortex, were you here yesterday
4 for Mr. Green's testimony and Mr. Kerrigan's testimony?

5 THE WITNESS: Yes, I was.

6 CAPTAIN LeGROW: Both -- Mr. Green testified,
7 if you recall, that the most he would expect in a wake
8 vortex encounter would be 30 degrees and I think you
9 testified the same thing here when Mr. Jacky was
10 questioning you.

11 THE WITNESS: Yes.

12 CAPTAIN LeGROW: You also said that the most
13 you'd expect would be 30 degrees in a strong vortex.
14 Could you define strong vortex, please?

15 THE WITNESS: I would say a strong vortex,
16 you know, is one that's where you're reasonable close
17 behind another airplane, like minimum separation. And
18 it's on a calm day and you're flying right through the
19 middle of it and it hasn't dissipated or started to
20 break up due to turbulence, so it's kind of a fresh
21 vortex and your minimum separation about another heavy
22 airplane.

1 CAPTAIN LeGROW: Could you tell us what
2 minimum separation between a 737 and 727 would be?

3 THE WITNESS: I really don't remember. I
4 don't know. Three miles?

5 CAPTAIN LeGROW: Three miles.

6 THE WITNESS: I think so.

7 CAPTAIN LeGROW: So if a 737 were four or
8 more miles behind a 727, you'd expect something less
9 than a 30 degree bank? Would that be a fair statement?

10 THE WITNESS: I really don't know. There's
11 so much variation and atmospheric dynamics that you
12 couldn't -- I don't think I could really say that.

13 I've seen, you know, you never -- I've seen
14 conditions where I never knew the airplane was even
15 there but I flew into it and it was kind of wiggle like
16 that. You know, five or 10 degrees. I knew it was a
17 vortex but I didn't know how old it was. I didn't even
18 see the airplane.

19 CAPTAIN LeGROW: Would it be safe to say that
20 you wouldn't expect 50 degrees of bank as represented
21 in Boeing's vortex video yesterday?

22 THE WITNESS: I never saw that in the

1 simulator test that I did.

2 CAPTAIN LeGROW: Thank you.

3 I have no further questions.

4 CHAIRMAN HALL: Any other questions from any
5 of the parties?

6 Does Boeing have any questions for this
7 witness? FM?

8 If not, Mr. Marx.

9 MR. MARX: Mr. Berven, could you explain to
10 me when you would use rudder during a flight and what
11 operations would you use it other than engine out? A
12 pilot, pilot input to the rudders.

13 THE WITNESS: Typically for a jet transport
14 or any type of jet airplane, the rudder is the least
15 used flight control. Typically, you use it for taxiing
16 and only if the engine is out. And sometimes you also
17 use it, depending on your technique, if you're landing
18 in a heavy crosswind. In that technique, basically,
19 you come down -- if you have a hard crosswind, say from
20 the left, you bank the airplane to the left so that the
21 left vector cancels the drift of the crosswind and then
22 you use the opposite rudder to keep the airplane

1 parallel to the direction of motion and you land it on
2 one wheel so that you don't get side forces on
3 touchdown.

4 So, for engine out, crosswinds and taxiing is
5 typically when you would use it.

6 MR. MARX: During the flight regime of 427 at
7 the time of the upset, would you expect any of the crew
8 members to be using rudder at all at this time?

9 THE WITNESS: No. I believe they were on
10 autopilot.

11 MR. MARX: If a wake vortex is encountered in
12 which there is a real upset of the airplane, what are
13 the pilots trained to do, or in your experience what
14 would you do as far as the rudders are concerned?

15 THE WITNESS: As far as the rudder?

16 MR. MARX: Rudder. Would you put any rudder
17 input into it?

18 THE WITNESS: Probably not because you
19 typically in a quick reaction situation or in an
20 emergency like that, you're not going to do anything
21 that you haven't already been doing. If you had enough
22 to react or a couple of seconds and you were in a

1 steady yaw, then you'd bring it back. But my reaction
2 when I run into a rolling vortex like that is just to
3 put the ailerons over real quick and stop the roll. But
4 it's so quick. You know, you're only in it a second or
5 two that you just oppose it as much as you can with the
6 aileron and it spits you out the side.

7 I don't think you would have time to think
8 about using the rudder. It might be instinctive, but I
9 don't know.

10 MR. MARX: Well, do you know of any training
11 where they would be training pilots to use rudder in
12 that situation?

13 THE WITNESS: No. I don't know.

14 MR. MARX: The exhibit that's up, the
15 viewgraph that's up there right now, you were speaking
16 to adverse rates where you take the rudder and move it
17 in one direction and the wheel in the opposite
18 direction.

19 I was a little bit confused. Maybe you can
20 explain it a little bit, but let's assume that we had
21 left rudder, full left rudder at the maximum rate and
22 we had full wheel compensating at its maximum rate to

1 the right. My understanding is that you said something
2 about 17 degrees per second in the direction of rudder.
3 Is that right? I mean, as if the rudder was -- it was
4 rolling in the direction of left roll?

5 THE WITNESS: That's correct.

6 MR. MARX: Okay.

7 THE WITNESS: It rolls into the direction of
8 the rudder initially.

9 MR. MARX: Because the rudder was more
10 powerful because of the fact that it's at a faster
11 rate?

12 THE WITNESS: Well, yes. Because of the
13 dynamic input of the rudder. But once that dynamic
14 input is over and the side that peaks and comes back
15 down to some lower value, then they usually balance
16 out. And the airplane, it rolls and winds up at about
17 a 45 degree stabilized bank for that condition.

18 MR. MARX: Would the autopilot be -- let's
19 assume that we would have a full left rudder deflection
20 for some reason and it was on autopilot. Would the
21 autopilot continue to control the airplane?

22 THE WITNESS: Well, the autopilot would

1 attempt to control the airplane but like the yaw
2 damper, the autopilot doesn't have full roll control
3 authority. It can't use full control deflection. I
4 think it only uses about 40 percent of the aileron.

5 So it -- in fact, when you do this maneuver
6 with the autopilot on, it rapidly puts the wheel
7 opposite to the roll in the direction of the rudder,
8 but it only uses about 40 to 50 percent of the roll
9 deflection so that the airplane continues to roll
10 rapidly into the rudder.

11 MR. MARX: Well, when you're on autopilot
12 though, would you expect the autopilot to compensate
13 the aircraft? I mean, at what point in time would you
14 know that you'd be getting into trouble with an
15 airplane?

16 THE WITNESS: Well, basically, like I said,
17 when we do an autopilot hardover, we require that for a
18 maximum rate input of a failure that affects the
19 attitudes of the airplane, that from pilot reaction and
20 three second later, it not roll any faster such that
21 you wind up more than a 60 degree bank. And what
22 happens when you do it with the autopilot on in this

1 maneuver is that it rolls very, very rapidly.

2 So, if you assume that the pilot is basically
3 doing his normal duties, you know, watching for
4 airplanes and using basically the navigation and the
5 ATC functions, if something like a full rudder hardover
6 occurred, you would notice immediately that something
7 was happening at the minute the airplane started to
8 roll. But it would take a couple of seconds to figure
9 out if in fact it was just a gust or something else was
10 going on.

11 And if you look at it, let's say
12 representative from what we saw in the simulator, the
13 airplane typically rolls to about 40 to 50 degrees
14 before you've figured it out and have disconnected the
15 autopilot. And at that point, you put the rest of the
16 aileron and it still continues to roll over to a steep
17 angle.

18 If you put the aileron in immediately, if you
19 disconnect the autopilot and slam it over as far as you
20 can go quickly, the airplane rolls to about 90 to 100
21 degrees and the nose drops to about 60, but you can
22 pull it back out. If you don't put in full aileron

1 immediately or if there's any delay in putting in
2 additional aileron, then it rolls all the way on over.

3 So the autopilot itself can't be designed
4 essentially for full 100 percent authority or they
5 couldn't pass the failure case. So the autopilot is
6 only about half authority or less. You'd only use half
7 wheel. But it did put in all it could.

8 MR. MARX: And you're also speaking of a
9 situation in a simulator where a pilot was putting in
10 full left or full right rudder control and what have
11 you and then catching it with aileron control. I think
12 you spoke of that in the beginning of your testimony.

13 I guess one of the questions I would have is
14 surprise. Whether a person is expecting this type of
15 thing to occur and the amount of time it takes to
16 recognize that you have a problem and to cause a
17 correction. And you were speaking before of about a
18 three second reaction time to occur.

19 Was this the type of stuff that this pilot
20 was taking into account? The fact that he would have
21 to have three seconds to react to this?

22 THE WITNESS: I guess I don't understand the

1 question.

2 MR. MARX: Well, the question is if you're
3 simulating a condition where he is putting a hardover
4 rudder into the simulator and then correcting with
5 roll, he was able to keep it -- my understanding was
6 that he was able to keep it from rolling over on its
7 back.

8 THE WITNESS: Oh, I see what your question
9 is.

10 MR. MARX: Yes. Now, he was assuming -- he
11 knew that this was coming.

12 THE WITNESS: Right.

13 MR. MARX: If you took into effect that you
14 didn't know it was coming and you had a reaction time
15 of three seconds to react to it, would you expect the
16 same result?

17 THE WITNESS: I would say no. If in fact --
18 we were basically disconnecting the thing at 50 to 60
19 degrees, which is basically when we got to it. There
20 was no intentional delay. If you catch it at 50
21 degrees and disconnect immediately and slam the
22 ailerons over, you can keep it up between 90 and 100

1 degrees.

2 I looked at some of the other data basically
3 and on the ones where you did the maximum rate hardover
4 and didn't put the ailerons in, if you waited four
5 seconds from the initiation of the failures, which is
6 basically what the Europeans do, they don't wait until
7 pilot recognition plus three. They just say it's one
8 second. It takes half a second to get the failure in
9 and half a second for the pilot to recognize it.

10 So if you do this maneuver assuming four
11 seconds from a hardover rudder with no pilot input like
12 you would do for an autopilot test, the airplane rolls
13 to about 120 degrees.

14 MR. MARX: That's over on its back.

15 THE WITNESS: Yes.

16 MR. MARX: Well, once again, I didn't finish
17 the question I had before with the 17 degrees left roll
18 -- 17 degrees per second when we were talking about the
19 adverse rate. That's the initial adverse rate. Is
20 there -- when you say initial, does that mean at the
21 very onset of the roll or are you talking about through
22 the roll, complete roll, to get to a certain degree?

1 In other words, is there an average? Would
2 it slow down? Would it start at 17 degrees per second
3 and go to five degrees per second and have an average
4 roll?

5 THE WITNESS: Well, basically the roll rate
6 has to build up. It's kind of a smooth curve. When
7 you first put in the rudder and opposite aileron it's
8 pretty much a smooth curve. It's parabolic. It goes
9 like this and accelerates and so that it comes down to
10 a maximum point. And that's what I'm talking about was
11 the maximum roll rate, which occurs -- it's a function
12 of the roll damping of the airplane and the amount of
13 control input. But it typically takes about a second
14 to a second and a half to maximum roll rate.

15 MR. MARX: What was the roll rate on the
16 actual accident airplane, this 427? Would it
17 correspond to that?

18 THE WITNESS: I remember that it's something
19 like around 10 to 12 degrees per second.

20 MR. MARX: Was the roll rate for the 427?

21 THE WITNESS: Yes.

22 MR. MARX: All right. Just one other thing

1 I'd like to -- the business with the degree per second
2 hardover on the rudder, we've heard testimony dealing
3 with five degrees per second, I think, from the Boeing
4 representative and you indicated about a 2-1/2 degrees
5 per second rate of change of rudder.

6 I don't know. Is this based -- the 2-1/2
7 degrees per second is based on what data? Boeing data?

8 THE WITNESS: You're talking about the
9 comparison to the FDR? What I said was that initially
10 we tried to match the heading rate. In other words, as
11 the airplane departed, it does the same thing. It
12 builds up to a certain rate and then comes back down
13 like this. So we're looking at -- if you put the
14 rudder in at 2-1/2 degrees per second, I'm just saying
15 that at a 2-1/2 degree per second hardover, the shape
16 of the heading departure looks the same. It doesn't
17 match it exactly but it's fairly close.

18 MR. MARX: That's with the full wheel
19 deflection that's trying to --

20 THE WITNESS: No. That's just the full
21 rudder.

22 MR. MARX: That's just full rudder?

1 THE WITNESS: Yes.

2 MR. MARX: So that's just a side slip?

3 THE WITNESS: It's a roll due to the side
4 slip and the yaw rate.

5 MR. MARX: I have no further questions.

6 CHAIRMAN HALL: Mr. Clark?

7 MR. CLARK: Mr. Berven, earlier there was a
8 discussion about steady heading side slip tests. And
9 in that, I think I misunderstood. I thought you said
10 that you don't test to full flight control input.

11 THE WITNESS: Not dynamically. We do
12 statically. In other words, we stabilize very slowly
13 until we reach full control deflection to see that the
14 rudder doesn't what I'll call overbalance or come up
15 with some reverse in the hitch moment. And also that
16 the aileron forces are proportional to the side slope.

17 MR. CLARK: Okay. That's what I meant.

18 THE WITNESS: We do go to full deflection but
19 not rapidly.

20 MR. CLARK: Okay. Thank you.

21 One other questions. In your experience with
22 your encounters with flight vortices and with the

1 simulation experience, would you expect the 737 to be
2 upset by the wake of a 727?

3 MR. CLARK: Not more than 30 degrees.

4 MR. CLARK: That's all I have. Thank you.

5 CHAIRMAN HALL: Mr. Schleede?

6 MR. SCHLEEDE: Thank you.

7 Mr. Berven, we're going to have some
8 testimony later in detail about the yaw damper system
9 on the 737. I wanted to ask you a few questions about
10 that before you get off.

11 Have you experienced maximum rate step input
12 yaw damper failures in flight?

13 THE WITNESS: Yes, I have. Intentionally for
14 the flight testing, but primarily the original test
15 that I did was in the 727-200, which was -- where the S
16 piece at 177 autopilot, which in fact should be worse,
17 because it was a four degree yaw damper at the time and
18 a lighter airplane.

19 Typically, the characteristics there are it's
20 a function of airspeed pretty much. In the approach
21 mode, for instance, if you're making a auto land and
22 you have a yaw damper hardover, it's hardly noticeable.

1 The autopilot rolls up about two to three degrees and
2 continues on to the auto land. It's just very benign.

3 On the other end of the spectrum up at VMO,
4 which is 365 knots indicated, I believe, it's a little
5 more of a reaction of the airplane. I believe for the
6 data shown there that you get about a third of the G,
7 lateral bump, so it jerks you off to the side and the
8 airplane rolled -- I believe it was 45 degrees with
9 pilot reaction. No. It was 49 degrees if they didn't
10 disconnect the yaw damper and 42 degrees if they did.
11 And that's with the three second delay from pilot
12 reaction.

13 In the middle range or the slow speed, like
14 we're talking about with flaps 1 and 190, the typical
15 hardover is very benign. It only rolls about 20
16 degrees or less.

17 MR. SCHLEEDE: Is that assuming a three
18 second response?

19 THE WITNESS: That's with a three second
20 delay after pilot reaction.

21 MR. SCHLEEDE: Regarding that system you
22 mentioned about turning it off, what is the procedure

1 for response to a yaw damper malfunction?

2 THE WITNESS: I don't believe -- I guess I
3 don't know. In flight tests basically we just oppose
4 it with the rudder after the three second delay. We
5 use aileron and rudder to recover from it.

6 MR. SCHLEEDE: Does the yaw damper, this type
7 of a malfunction something that's considered during
8 your responsibilities in flight tests for handling
9 qualities?

10 THE WITNESS: Yes.

11 MR. SCHLEEDE: Is it something that's
12 considered for certification of the aircraft?

13 THE WITNESS: Yes. We do that as a part of
14 the automatic flight control system evaluation. We do
15 autopilot hardovers and yaw damper hardovers throughout
16 the flight envelope of the airplane.

17 MR. SCHLEEDE: How would you characterize
18 step input yaw damper malfunctions? Would you consider
19 them a safety problem for flight safety?

20 THE WITNESS: I guess depending on where you
21 were and whether you were standing up or not. At
22 cruise flight with a yaw damper hardover, it will

1 knock you over if you're in the back of the airplane,
2 but it's not a hazard from the safety standpoint of the
3 airplane, no. It not an uncontrollable maneuver for
4 the pilot, although it is uncomfortable and quite a
5 good jerk.

6 MR. SCHLEEDE: Have you participated in 737
7 flight tests of thrust reverse deployments in flight?

8 THE WITNESS: Yes, I have.

9 MR. SCHLEEDE: Can you describe those briefly
10 for us?

11 THE WITNESS: Basically, the maneuver we do,
12 -- if I can remember this. The maneuver we do is
13 basically to assure that if the thrust reverse comes
14 out that you can continue with safe flight and landing.
15 And we do this at about -- I believe it was about 200
16 knots where we put a -- and normally you can't do that
17 because it's locked out due to the air ground switch.
18 But we put in a modification to allow us to do that.
19 So, we stabilized the airplane at idle on one engine
20 and around 200 knots -- it varies with the airplane --
21 and extend the thrust reverse to its full deflected
22 position with the engine at idle. And we look at the

1 operational characteristics of the airplane; whereas,
2 how much roll, how much yaw, how much buffet.

3 And basically, we only do that at idle
4 because there's basically what we call a throttle
5 snatcher in the control system such that if the reverse
6 unlocks, it pulls the idle -- the throttle, all the way
7 back to idle immediately.

8 So we look at that characteristic and,
9 depending on the airplane, -- as I remember on the 737
10 it's not a significant problem. There is some buffet
11 and roll but you can continue the airplane, continue
12 safe flight and landing even if you don't shut the
13 engine down.

14 MR. CLARK: And this throttle snatcher, is
15 that system installed on the 737-300?

16 THE WITNESS: Yes. I believe so.

17 MR. SCHLEEDE: During those various tests
18 that you described with Mr. Jacky and the hardover
19 simulations, did you note anything that would cause you
20 to question any of the decisions made on the original
21 certification of this airplane?

22 THE WITNESS: No, not at all. The aircraft

1 met all of the airworthiness rules handily and really
2 flies quite nicely.

3 MR. SCHLEEDE: Thank you very much.

4 CHAIRMAN HALL: Mr. Laynor?

5 MR. LAYNOR: Just a couple, Mr. Berven. I
6 think clarification.

7 I'm not quite sure I understood the extent to
8 which you test hardover flight controls beyond the
9 autopilot authority. I think you said you did not test
10 dynamically but you did test statically.

11 What regulatory requirements assure
12 protection against a non-tested control deflection?

13 THE WITNESS: I'm not an expert on failure
14 modes and effects analysis, but based on my basic
15 knowledge and what I think that happens on this
16 airplane is that basically the flight control systems
17 aren't tested. The primary flight controls are not
18 tested for hardover testing because they have so much
19 control power by the nature of the design that you
20 could lose the airplane if you do that.

21 Therefore, the initial intent is that you
22 can't have that happen. Basically, the flight control

1 systems have to be as safe and prevented from hardovers
2 as the basic structure of the airplane.

3 I believe that the certification basis for
4 the 737 says that you can't have any single failure or
5 any latent failure plus one more that would cause you
6 not to be able to continue safe flight and landing.
7 And basically, their failure analysis shows that.

8 So our impression is that a primary flight
9 control system hardover is impossible and has to be
10 impossible.

11 MR. SCHLEEDE: Okay. So it's airworthiness
12 redundancy requirements that are the protection.

13 Is the yaw damper a required piece of
14 equipment in the 737 per dispatch?

15 THE WITNESS: I believe it is. And you can
16 dispatch it to a certain altitude, but I'm not an
17 expert on that. I don't remember. I think it is
18 required.

19 MR. SCHLEEDE: Are the handling qualities of
20 the airplane satisfactory without the yaw damper for
21 normal landing, takeoff and cruise situations?

22 THE WITNESS: Yes, they are.

1 MR. SCHLEEDE: You mentioned yaw damper
2 hardover. It would typically, perhaps roll the
3 airplane to about 15 degrees before the pilot reacted
4 and stopped that roll.

5 Now, you didn't say what kind of roll rate
6 might be associated with that. Is that --

7 THE WITNESS: I really don't know what that
8 would be. You're looking at a very non-linear event
9 there. Just about the time the roll rate peaks is when
10 you recover, so it's basically continuously changing
11 from zero to whatever the maximum would be and you'd
12 wind up with an average that would give you essentially
13 15 degrees in 3-1/3 seconds, whatever that is. It's
14 not very fast.

15 MR. SCHLEEDE: All right. And only one more
16 for clarification.

17 In the description for the exhibit that's
18 still up on the screen back there, what speed were the
19 roll rate tests made that were described under Number
20 10 on that exhibit?

21 THE WITNESS: These are all done at 190 knots
22 with flaps 1.

1 MR. SCHLEEDE: 190 and with flaps at 1?

2 THE WITNESS: That's right.

3 MR. SCHLEEDE: Okay. The accident condition?

4 THE WITNESS: That's correct.

5 MR. SCHLEEDE: Thank you very much, Mr.

6 Berven.

7 CHAIRMAN HALL: Again, just a few questions.

8 I appreciate your time up here.

9 You earlier described a side slip and I
10 believe the accident flight itself was in a turn, it
11 appears, at the time this encounter happened. How does
12 a side slip or a turn affect the authority of the yaw
13 damper or the rudder in a hardover?

14 THE WITNESS: I guess I don't understand that
15 question. Typically in a turn the autopilot, basically
16 the airplane is flying pretty narrow at zero side slip,
17 so that autopilot -- the yaw dampers is working plus or
18 minus about that to keep it at zero, to keep the yaw
19 rate to zero in any case.

20 CHAIRMAN HALL: In a side slip you wouldn't
21 get any more authority out of the yaw damper in terms
22 of --

1 THE WITNESS: No. It would be the same.

2 CHAIRMAN HALL: It would be the same. Okay.

3 Is there anything in your opinion besides the
4 rudder that could give a roll rate consistent with the
5 trace on the flight data recorder?

6 THE WITNESS: Based on all the testing we
7 did, that was the only control that would cause it to
8 roll that fast.

9 CHAIRMAN HALL: Okay. And let me see. Your
10 testing that you do for certification, do you have the
11 autopilot on when you try these hardovers or are you
12 hand flying the plane?

13 THE WITNESS: Well, we don't do any hardovers
14 with the autopilot off. As I pointed out, we don't do
15 primary flight condition hardovers. When we do the
16 autopilot hardovers, we're not -- we have no hands on
17 the controls. Basically, we're using a stopwatch.
18 Somebody in the back initiates the yaw damper servo
19 hardover and I wait until I see something and then I
20 count mark 1002, 1003 and then recover from whatever
21 maneuver that they input.

22 What you typically do at the end of that

1 three seconds, you disconnect the autopilot and then
2 recover back to level flight.

3 CHAIRMAN HALL: Mr. Berven, in my opinion you
4 have done an excellent job of representing the Federal
5 Aviation Administration. You've been a good witness.
6 Thank you very much. You're excused.

7 THE WITNESS: Thank you.

8 (Witness excused.)

9 CHAIRMAN HALL: The next witness we will call
10 is Mr. Michael Carriker. If Mr. Carriker could
11 approach, he is a Senior Engineering Project Pilot on
12 the 737. He is with the Boeing Commercial Airplane
13 Group out of Seattle, Washington.

14 (Witness testimony continues on the next
15 page.)

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1 MICHAEL CARRIKER, SENIOR ENGINEERING PROJECT PILOT 737
2 BOEING COMMERCIAL AIRPLANE GROUP, SEATTLE,
3 WASHINGTON
4

5 (Whereupon,

6 MICHAEL CARRIKER,
7 was called as a witness by and on behalf of NTSB, and,
8 after having been duly sworn, was examined and
9 testified on his oath as follows:)

10 MR. SCHLEEDE: Mr. Carriker, could you give
11 us your full name and business address for the record?

12 THE WITNESS: Michael Carriker, Boeing
13 Commercial Airplane Group, Post Office Box 3707,
14 Seattle, Washington.

15 MR. SCHLEEDE: What is your position with
16 Boeing?

17 THE WITNESS: I'm a Senior Engineering Test
18 Pilot, Engineering Project Pilot, assigned to the 737.

19 MR. SCHLEEDE: How long have you worked for
20 Boeing?

21 THE WITNESS: Five years.

22 MR. SCHLEEDE: Could you briefly describe

1 your education and background?

2 THE WITNESS: I have a B.S. in aeronautical
3 engineering. I spent 12 years in the United States
4 Navy, a graduate of the United States Navy Test Pilot
5 School and an instructor at the Navy Test Pilot School
6 and an instructor at the Empire Test Pilot School in
7 Boscombe Down, England.

8 Since coming aboard for Boeing, I have type
9 ratings in all the current production airplanes and a
10 provisional type rating in the 777. I'm flight
11 instructor qualified in the 737 and the triple 7.

12 MR. SCHLEEDE: Roughly, how much total flying
13 time do you have?

14 THE WITNESS: About 4,700 hours of flight
15 time.

16 MR. SCHLEEDE: Is that mostly flight tests?

17 THE WITNESS: About 3,000 of it.

18 MR. SCHLEEDE: How much, roughly, do you have
19 in the 737?

20 THE WITNESS: 1,300.

21 MR. SCHLEEDE: Thank you very much.

22 Mr. Jacky will proceed.

1 MR. JACKY: Good morning, Mr. Carriker.

2 THE WITNESS: Good morning.

3 MR. JACKY: I want to ask you first of all in
4 what capacity did you participate in the investigation
5 of the accident in 427?

6 THE WITNESS: Initially I was assigned to the
7 Operations Group. On the morning of the accident it
8 became apparent that the Operations Group had enough
9 people. They weren't going to actually go to the
10 scene. I requested permission to join the Cockpit
11 Voice Recorder Team, so I went to Washington, D.C. and
12 participated in that regard.

13 When they came back to Seattle to start doing
14 the simulator evaluations, my position of being on the
15 CVR team and aware of the accident and my job as being
16 a 737 engineering pilot, I assisted the Performance
17 Group in the simulations.

18 MR. JACKY: When the FM is performing
19 certification flights for certain aircraft,
20 specifically Boeing aircraft, are Boeing pilots
21 represented in those tests?

22 THE WITNESS: Yes. At all times. The

1 sequence of events is that the Boeing Company goes out
2 and performs the tests. And like Mr. Berven said, when
3 we're ready to demonstrate the airplane, we get what's
4 called from the FM a type inspection authorization and
5 then a Boeing pilot goes along with an FM pilot from
6 the Aircraft Certification Office and we demonstrate to
7 them. It's the FAA's choice whether they want to watch
8 or if the FM pilot wants to fly it. That's a decision
9 made on a case by case basis. And then the airplane's
10 performance flying qualities are demonstrated to comply
11 with FAR Part 25 regulations.

12 MR. JACKY: You mentioned the FM's Aircraft
13 Certification Office. would that be the office in
14 Seattle?

15 THE WITNESS: There is one in Seattle. Yes.

16 MR. JACKY: And would that generally be the
17 particular group that Mr. Berven works with?

18 THE WITNESS: Yes.

19 MR. JACKY: Okay.

20 THE WITNESS: I hope I have all my FM terms
21 correct.

22 MR. JACKY: Did you have an opportunity to

1 participate in the FM -- let me back up for a minute.

2 In the simulator studies that were performed
3 for the Aircraft Performance Group and also previous to
4 that for the FM, the studies were performed in
5 Boeing's en-cab simulator. Is that correct?

6 THE WITNESS: That's correct. We have an M,
7 that stands for multipurpose cab. Like Mr. Kerrigan a
8 little bit yesterday, it is a generic airplane
9 simulator. We can change the parameters very easily in
10 the simulator. It has the exact database that goes
11 into any simulator, but we know the individual
12 coefficients of the aileron, the spoilers, the rudders,
13 and we can control those variables.

14 So if we want to in this case simulate a
15 fault, then we can instruct the computer to take that
16 part out or add that part into the simulator database,
17 the program that calculates the numbers that display in
18 the cockpit so we can make these changes and we can
19 make them incrementally.

20 We can also input those faults from the
21 outside so the pilot doesn't have to step on the rudder
22 peddle at 2-1/2 degrees per second. We know that it

1 goes in and we know that it goes in at the right time
2 and the correct rate.

3 MR. JACKY: And how are those inputs
4 controlled again?

5 THE WITNESS: We have a computer operator.
6 The simulator operator just types them in, changes the
7 variables in the computer program and lets them go.
8 And they know from their aerodynamic data how to change
9 the variables.

10 MR. JACKY: There was some talk yesterday
11 about the comparison between an engineering simulator
12 and an airline training simulator, I believe. In your
13 opinion, how do those compare?

14 THE WITNESS: From a flying quality
15 standpoint and a handling standpoint, there is no
16 difference. We don't need to have radio panels in
17 there. We don't need to have a transponder panel.
18 We're not looking at those things. We actually have a
19 different simulator to do lighting evaluations.

20 The multipurpose cab is there for flying
21 qualities analysis, systems failures analysis, things
22 like that.

1 MR. JACKY: Did you happen to hear Mr.
2 Berven's testimony?

3 THE WITNESS: Yes.

4 MR. JACKY: And were you present when the FM
5 performed the simulator test at the Boeing M cab?

6 THE WITNESS: Yes. Mr. Berven was in the
7 left seat and I was in the right.

8 MR. JACKY: I don't necessarily need for you
9 to go through each and every one of the tests that were
10 performed in that simulator session, but could you
11 characterize the simulated failures that were run?
12 Well, can you characterize the simulator failures that
13 were run?

14 THE WITNESS: They were the same general
15 scenarios that we had for the first Performance Group
16 investigation, although we couldn't put the rates in.
17 We had to manually put these rates in. And what we
18 were interested in looking for were, as Mr. Berven
19 said, you know, hardover rates, the type of recoveries,
20 what it takes to look at, what effects, you know, what
21 is the visual scene outside the airplane, what cues did
22 the pilot have. Also interested in where the simulator

1 would result. You know, what results the simulator
2 would get back out.

3 We found that with the data in the simulator,
4 as Mr. Kerrigan said yesterday, when you get to these
5 very high angles of side slip, 10, 12, 15 degrees of
6 Beta and then you also put the airplane up to 3 and 4
7 G's and put it above the stall of the airplane, the
8 simulator -- we don't know how valid our simulator
9 model is after that point in time because we don't have
10 any flight test data. We've never spun the airplane.
11 We've never put in full rudder peddle and full left
12 stick.

13 MR. JACKY: And how would you characterize
14 the results of this test? We still have the sheet up
15 from Exhibit 13-B and you mentioned that the tests that
16 were performed in the FM simulator session were
17 comparable to the ones ran in the first Aircraft
18 Performance Group session?

19 THE WITNESS: Yes, except that they weren't
20 quite so controlled.

21 MR. JACKY: Okay.

22 THE WITNESS: We didn't have the specific

1 points.

2 MR. JACKY: And without necessarily going
3 through each of the test, how would you characterize
4 the results of these tests?

5 THE WITNESS: I agree with -- Mr. Berven made
6 some points that when you fly the airplane and you put
7 in a -- put in slow rudder rates and proper recoveries,
8 the airplane flies like you'd expect any airplane to
9 fly. You have control power. The airplane responds to
10 what the input is.

11 We saw that if you delay a reaction or if you
12 don't put in a full and proper authority reaction to
13 what's happening then the recovery is markedly
14 different than if you put in full timely controls.

15 We tried lots of things also. We didn't have
16 a great idea of what had happened at that point in
17 time, what had happened in the accident, so we were
18 trying to match scenarios. What does this do if we do
19 this? Let's look at the results. It comes out the
20 other side. Does that match the flight data recorder?
21 Well, no, it doesn't. And that would help eliminate
22 possibilities.

1 MR. JACKY: Is it your opinion that any one
2 of these tests might have replicated the FDR traces at
3 least initially of the upset?

4 THE WITNESS: We can't find the -- on these
5 tests that we did for the FM and for the first time
6 that the Performance Group was there, none of them
7 really replicates the whole event. That's why we went
8 with the vortex simulation because we can't get a
9 single failure that causes the initial oscillation
10 between the 7 degrees and back to 30 and back in 18-19
11 degree range and back over.

12 But then we knew that some sort of yawing
13 input was put in and it was added by a rate, a slow
14 rate as compared to what the possibility of it is. And
15 we found that the 2-1/2 degree and the 5 degree per
16 second rudder input rates matched from a qualitative
17 standpoint. From a pilot standpoint sitting in a
18 simulator and reading the flight data recorder, they
19 were matching each other.

20 But the .5 degree per second was too
21 slow. The rudder hardover rate when it runs at 52
22 degrees a second exhibits -- it has to -- if it yaws

1 very much, you'd get a very definitive heading change
2 before the airplane rolls.

3 MR. JACKY: Did you participate in the
4 simulations of the wake vortex model?

5 THE WITNESS: Yes, I did.

6 MR. JACKY: And what was your experience on
7 the quality of Boeing's model of the wake vortices?

8 THE WITNESS: I thought it was very good.
9 I've never seen a wake vortex. The five or six
10 encounters that I've had in a 737, it matched it very
11 well. It's what you'd expect.

12 We tried several different events to prove to
13 ourselves that it worked well. We didn't always start
14 on the left side and stick the right wingtip into the
15 vortex. We started in the middle of the vortex, put
16 the center of the gravity of the airplane in the middle
17 of the vortex, and watched it have this pure rolling
18 moment, which was indicative of what we had.

19 So, we could verify that the simulation was
20 as good as any simulation we have ever had.

21 MR. JACKY: So qualitatively the results
22 would be similar to what you've experienced in flying?

1 THE WITNESS: Yes. And I did that from -- I
2 know that the times that I've known what the vortex
3 was, we do a flight test technique called a wind up
4 turn. It's to look for stability characteristics in
5 the airplane. But in those cases you do a very rapid
6 360 degree turn and you cross back through your own
7 vortex and then you get that thumb that Mr. Berven was
8 talking about. And that's definable. You know that
9 you're the one that caused it.

10 And so we did the same sort of test here and
11 we got the same reaction. Remember that we can't
12 really predict upon the vertical acceleration in the
13 cab because there are hydraulic jacks and rams and
14 there's limited authority. But the gauges displayed
15 the same sort of vertical G bump that you'd expect to
16 have in the airplane. Plus the motion simulator is
17 very good and it also helped out.

18 MR. JACKY: Have you ever experienced a wake
19 vortex trailing behind another aircraft?

20 THE WITNESS: Yes.

21 MR. JACKY: Could you characterize the
22 duration of that experience?

1 THE WITNESS: They are in the one or two
2 second time frame. The ones that I've had behind
3 another airplane trail is landing behind 747's and
4 getting rolled due to that. And it's basically that
5 the airplane rolls rapidly, but at the same time the
6 lift vector of the airplane has a tendency to take you
7 right out of the vortex. So you get this rather -- you
8 get a rapid rolling moment, but then at the same time,
9 that rolling moment also takes the vector of the
10 airplane and takes it out of the vortex.

11 So you get this rolling moment and then it's
12 done and you're left at some 20-30 degree bank angle
13 from which you recover from.

14 MR. JACKY: Are you familiar with the yaw
15 damper system on the 737 aircraft?

16 THE WITNESS: I have general familiarity with
17 it.

18 MR. JACKY: Is it your experience that you
19 can feel the yaw damper actively moving during normal
20 operation?

21 THE WITNESS: During normal operations, no,
22 you can't. Sometimes you can perceive it working. In

1 a turbulent situation you can possibly feel it working,
2 but it's very hard to distinguish between the yaw
3 damper working and outside turbulence.

4 There is a gauge in the cockpit and I can't
5 quite make sure if it's a customer option or if it's
6 there and it actually shows a yaw damper actuating, but
7 it's not a normal item that you scan.

8 MR. JACKY: You mentioned gauges in the
9 cockpit. Are there any gauges in the cockpit that
10 would indicate the position of the different control
11 surfaces on the 737?

12 THE WITNESS: No. There's trim position
13 indicators for the airplane but to look at the elevator
14 position, the rudder position and the aileron position
15 you'd have to look at your feet and your hands.

16 MR. JACKY: In your experience in the 737,
17 have you ever encountered an in-flight thrust reverser
18 deployment?

19 THE WITNESS: Yes. Yes, I have.

20 MR. JACKY: And could you characterize what
21 that experience would be?

22 THE WITNESS: The test that we did it, we did

1 it at 250 knots at the beginning with the engine at
2 idle and you have to bypass the safety systems and open
3 it up.

4 Even though I was the one that opened up the
5 thrust reverser, it was a -- it's very loud. There's a
6 lot of buffeting and vibration in the airplane. It's
7 controllable. A little bit of rudder peddle and a
8 little bit of aileron stops the roll rate and you can
9 fly with it.

10 What was interesting to me was the amount of
11 noise and shaking in the airplane that went on when
12 that thrust reverser opened up. And we continued down
13 to flaps 1 and 210 knots. We got down to flaps 5 and
14 decided to shut the engine, to close the reverser bay.

15 MR. JACKY: Do you know whether the thrust
16 reverser deployed all the way?

17 THE WITNESS: Yes. It deployed all the way.

18 MR. JACKY: And did you feel any appreciable
19 yaw moment as a result of that deployment?

20 THE WITNESS: Yes.

21 MR. JACKY: You said that you were a member
22 of the Cockpit Voice Recorder Group. Is that correct?

1 THE WITNESS: That's correct.

2 MR. JACKY: And as a member of the cockpit
3 voice recorder group, did you have an opportunity to
4 listen to the CVR take from this?

5 THE WITNESS: Yes.

6 MR. JACKY: Was there any sounds or noises
7 during the listening of the tape that would be
8 indicative in your experience of a thrust reverser
9 deployment?

10 THE WITNESS: No.

11 MR. JACKY: I have no further questions.

12 CHAIRMAN HALL: Thank you.

13 Any questions from the parties?

14 I only see a hand from Boeing.

15 Any other party have a question? If not, Mr.
16 Purvis, please proceed.

17 MR. PURVIS: Mr. Carriker, we have a couple
18 of questions for you.

19 You were just talking about the thrust
20 reverse in-flight deployment. Would the throttle snatch
21 system bring the engine parameters down that would be
22 observable on the FDR?

1 THE WITNESS: Yes. We didn't -- in our
2 flight test we didn't test that system. We were
3 testing for flying qualities with the thrust reverser
4 open, so in a controlled test, we put the throttle at
5 idle and then opened up the thrust reversers. But the
6 system is designed to bring the throttle back to idle
7 if the thrust reverser opens.

8 MR. PURVIS: And on the accident airplane, if
9 it came open, you would have seen it on the --

10 THE WITNESS: Yes.

11 MR. PURVIS: -- flight data recorder?

12 THE WITNESS: Yes. It would be been
13 independent of the other engine.

14 MR. PURVIS: Thank you.

15 I'd like just to clarify that you flew these
16 flight simulations that are shown on Exhibit 13-B, page
17 4 that's on the viewfoil machine?

18 THE WITNESS: That's correct.

19 MR. PURVIS: In the Item 2 that's called
20 Rudder Hardover Rates, was the airplane traveling at
21 the accident -- or at the 190 speed and 1 degree flaps?

22 THE WITNESS: Yes. The test conditions on

1 all these performance tests that the Performance Group
2 did, the test conditions were the same altitude, same
3 airspeed, same flap configuration setting. The
4 airplane had the same gross weight. The airplane had
5 the same center of gravity and we had the same systems
6 built in the airplane so that we'd know that fact.

7 MR. PURVIS: For the Condition A where it
8 shows half a degree per second rudder hardover rate,
9 was the airplane fully recoverable under those
10 conditions?

11 THE WITNESS: Yes. The rate is so slow in
12 that case that you just watch it for a few seconds and
13 you kind of say, you know, "What's going on there?"
14 The autopilot comes in and the autopilot counteracts it
15 easily in the beginning and then you have time to
16 analyze it and take it off. And then your feet, if you
17 have your feet on the rudder peddles, your feet are
18 moving.

19 MR. PURVIS: And a similar question for the
20 2-1/2 degree/second. Was it fully recoverable under
21 those circumstances?

22 THE WITNESS: Yes.

1 MR. PURVIS: And for the 5 degree/second
2 rate?

3 THE WITNESS: When you're talking about in
4 the 5 and the 10 and the hardover rate, all these
5 events are recoverable events.

6 MR. PURVIS: Okay.

7 THE WITNESS: I guess to expound upon that,
8 the recovery, it would be as Mr. Berven said. You
9 would see probably 90 degrees angle of bank, but as
10 long as you put it in full opposite flight controls and
11 you flew the airplane to the best of its ability, you
12 would roll out. You would out and go back to wings
13 level.

14 MR. PURVIS: Okay. I want to move on to the
15 yaw damper system. On the 737-300 is the yaw damper
16 system required for dispatch?

17 THE WITNESS: No. On the 200 airplane it was
18 required for -- you couldn't fly with the autopilot on
19 above -- 30,000 feet strikes me. But in the 737-300,
20 -400 and -500, the yaw damper is not required for
21 flight.

22 MR. PURVIS: In your experience with

1 encountering wake vortex, can you get more than 30 or
2 40 degrees of airplane roll?

3 THE WITNESS: Yes. It depends how you put
4 it. In a model, we've seen that. We know from doing
5 their student once. Boeing did a test of flying behind
6 a 747 with a 737 in the 1970's and that airplane rolled
7 up to about an 80 degree angle of bank in a worst case
8 scenario. In our tests that we performed, we had to
9 play with it quite a bit, but if you made the
10 parameters just right, you would see in the 50 degree
11 range of a bank angle.

12 And that was getting into one vortex and
13 having it spit you back into the next and you coupled
14 up the events. If you just started in the middle of a
15 high vortex and turned the simulator on with the center
16 of gravity of the airplane parked in the middle of the
17 vortex, you would get in the 50 degree range.

18 MR. PURVIS: You participated in the recent
19 test where the NTSB groups used the CVR coupled with
20 the simulation?

21 THE WITNESS: That's correct.

22 MR. PURVIS: What was your impression of that

1 experiment?

2 THE WITNESS: The impression was, one, that
3 it brought back into focus the time that the event
4 happened. It could have added awareness to having the
5 cockpit voice recorder looking at an airplane that does
6 this same scenario, the same thing the flight data
7 recorder said it did, and it lended (sic) more emphasis
8 to listening to the tape to try to get any noises and
9 to see if it could capture anybody's ideas of what some
10 of the unidentified noises were -- are.

11 MR. PURVIS: Based on your participation in
12 that test, do you have any recommendations for the
13 future, such as using it earlier or anything?

14 THE WITNESS: I thought it was very
15 beneficial. I think the people that got the most out
16 of the test were the people that were actually on the
17 cockpit voice recorder team because we already knew to
18 ignore some of the voice comments, the radio comments
19 that we already knew and that we could listen to the
20 background noises to try to pick these things out.

21 Of course, I think some of the folks that
22 hadn't listened to the tape prior spent a lot of time

1 just listening to the voices and couldn't pick up --
2 couldn't ignore those points.

3 Also, we listened to a very small part, about
4 a minute's worth, and people couldn't recognize voices
5 and that kind of effect. So one of the points we
6 brought out was to maybe play four or five minutes once
7 prior to it so you'd get the setting of the idea, the
8 concept of what's going on in the cockpit.

9 MR. PURVIS: How about timing wise during the
10 investigation, the doing of this test? Do you have any
11 recommendations there?

12 THE WITNESS: It could have been done
13 earlier. Sometimes we have -- since we have an idea
14 that this is a benefit, it could be done earlier in the
15 tests to eliminate a lot of questions that were
16 floating around. You know, of what if, and does this
17 and do that. Because like myself, I couldn't answer my
18 own company's questions because I was sworn not to tell
19 anybody what was on the CVR.

20 MR. PURVIS: Thank you.

21 Mr. Chairman, I have no more questions.

22 CHAIRMAN HALL: Thank you.

1 Any questions, additional questions from the
2 parties?

3 The Airline Pilots? Yes, sir, Captain.

4 CAPTAIN LeGROW: Thank you, Mr. Chairman.

5 Good morning, Mr. Carriker.

6 You made reference to the vortex simulations
7 that we done at Boeing. Is it my understanding from
8 Mr. Kerrigan's testimony yesterday that those were done
9 with the suspended vortex, both vertically and
10 horizontally?

11 THE WITNESS: Suspended? I guess I don't
12 understand suspended vertically and horizontally.

13 CAPTAIN LeGROW: Well, if I recall Mr.
14 Kerrigan's testimony yesterday when the model was made
15 for the video that was produced by Boeing, that the
16 vortex was suspended and then the maneuver was done
17 with a suspended vortex.

18 THE WITNESS: Oh, that's correct. I guess
19 maybe I could explain a little bit better how we did
20 this simulation. I think people had an idea how we had
21 to break the airplane up into pieces so that we could
22 model the flow in individual increments across the

1 airplane because you can put your right wingtip into
2 the flow and there's no effect on the left wingtip. So
3 we needed to have this to break this down.

4 But the vortex, we could model the velocity,
5 basically the rotational velocity of the vortex and we
6 could start at zero in the middle and then it rises to
7 its peak and I think we ended up at four feet. And
8 then it decays with the inverse of the radius of the
9 vortex after that. And they are perfect vortexes.

10 In our simulation, the vortexes were rapidly
11 descending but the value of the vortex was always
12 constant. And our visual simulation went along for
13 about five minutes or so before we actually ran out of
14 the visual, although the vortex would calculate -- it
15 would calculate the vortex forever.

16 So we had the ability in the simulator to
17 start the event wherever we wanted to. We could start
18 it above the vortexes; below it; left or right; or,
19 like I stated, directly inside the vortex. And we
20 could find the vortex. That's one thing that we noted
21 before. That if you don't identify the vortex in the
22 visual then you can't find it. And it's too difficult

1 to read a series of numbers to know where you are.

2 So we put the visual out there. The outside
3 picture that you saw yesterday was an outside camera
4 view. From inside the cockpit, we could look over and
5 see or look up and see these two gold and purple tubes
6 in the sky with a red bar down the middle that
7 signified the centerline of it. And we did fly into it
8 from any position we wanted.

9 We could start the simulator from any
10 position we wanted to and then fly into it; hand fly
11 into; let the autopilot fly into it however we wanted
12 to get into the simulation.

13 CAPTAIN LeGROW: In your opinion is this
14 something that would be representative of an actual
15 encounter?

16 THE WITNESS: Yes. If you had a perfect
17 vortex out there, yes, it would be. And, you know, you
18 can turn one off. Actually, the more realistic one was
19 to turn one of the vortexes off and then just run into
20 one. And that was very representative of what you'd
21 expect.

22 Normally, -- I can't ever say that I've been

1 in a vortex where I got full left and I knew that the
2 vortex rolled me back to the right; whereas, in this
3 case we could watch it, very definitively watch all
4 these motions.

5 CAPTAIN LeGROW: Did Boeing produce a video
6 with a single vortex?

7 THE WITNESS: I don't think so.

8 CAPTAIN LeGROW: You testified a few minutes
9 ago that you've encountered in actual flight vortexes.
10 Is that correct?

11 THE WITNESS: Yes.

12 CAPTAIN LeGROW: And you described them as
13 something of an 80 degree bank, if I recall?

14 THE WITNESS: No. I quoted a Boeing flight
15 test from the early '70s where they flew a 737-200
16 purposely behind a 747 and rolled the airplane up.

17 CAPTAIN LeGROW: Do you recall at what
18 distance that was?

19 THE WITNESS: No, I don't. About a minute.

20 CAPTAIN LeGROW: In your experience as a
21 professional pilot have you encountered a wake vortex
22 from a 727?

1 THE WITNESS: No.

2 CAPTAIN LeGROW: Thank you, Mr. Chairman. I
3 have no further questions.

4 CHAIRMAN HALL: Thank you. Does that
5 conclude the questions from the parties?

6 (No response.)

7 If so, Mr. Marx.

8 MR. MARX: During the simulation testing that
9 was performed, were the pilots that were flying the
10 simulator, where did they have their feet?

11 THE WITNESS: On the rudder peddles.

12 MR. MARX: During normal flight of a 737
13 would you be expected to have your feet on the rudder
14 peddles?

15 THE WITNESS: We'd normally expect to have
16 the pilots' feet on the floor in the front of the
17 rudder peddles or on the rudder peddles.

18 MR. MARX: Is there any other position that
19 the pilots' feet could be besides on the floor or on
20 the rudder peddles?

21 THE WITNESS: Oh, sure, there is, but it
22 would be what you would think to be a proper pilot

1 position.

2 MR. MARX: I mean, is there a foot rest that
3 they have in the cabin where you can put your foot up?

4 THE WITNESS: No. There's not a specific
5 foot rest inside the airplane.

6 MR. MARX: It's not. But is it used as a
7 foot rest?

8 THE WITNESS: Yes.

9 MR. MARX: Is it commonly used as a foot
10 rest?

11 THE WITNESS: It wear out a lot. Yes.

12 (Laughter.)

13 MR. MARX: Well, I'm trying to get an idea if
14 pilots normally would fly with their feet on the rudder
15 peddles and the consensus I'm getting here is that they
16 don't. They have their feet on the floor.

17 Is that different than what --

18 THE WITNESS: I think it has to do with the
19 phase of flight. You could say in this phase of flight
20 where 427 was, that the pilots would have had their
21 feet on the floor or on the rudder peddles. It's
22 10,000 feet. They're ready to land. They've done all

1 their proper briefings. It's not 35,000, three hours
2 left to go before they start their top of descent.
3 That's when you'd expect maybe for the pilot to have
4 his feet not on the peddles or on the floor right in
5 front of the peddles. But when they start the top of
6 descent, the airplane starts coming down, the activity
7 picks up, the requirements to fly the airplane are very
8 apparent and you'd expect the pilot to have his feet in
9 the location of the rudder peddles.

10 MR. MARX: Well, if the pilot had his feet on
11 the floor and you had a runaway rudder, would he know
12 it?

13 THE WITNESS: If you have a runaway rudder,
14 you would have a four inch displacement, plus or minus,
15 for the rudder peddles. There'd be an eight inch
16 difference between the rudder peddles.

17 I guess if you have your -- that's a
18 question. If your feet are right there, it would hit
19 your ankles with the rudder peddle.

20 MR. MARX: It would come at hit your ankles?

21 THE WITNESS: Well, if your foot is within
22 four inches, was stationed within four inches of the

1 rudder peddles.

2 CHAIRMAN HALL: Mr. Clark?

3 MR. CLARK: Mr. Carriker, have you
4 participated in any flight tests where an attempt was
5 made to duplicate this accident scenario or portions of
6 it?

7 THE WITNESS: I participated in a flight test
8 where we looked to get extra data to try to verify our
9 simulator model as to what would happen if you had a
10 roll rate and then you added a rudder input on top of
11 that.

12 MR. CLARK: Would you describe those tests?

13 THE WITNESS: We took a 737-300 airplane;
14 went out -- we actually did it at 35,000 feet. We were
15 at flaps 1, 190 knots. I rolled the airplane to 7 to 8
16 degrees per second rate of roll. At 45 degrees left
17 wing down, I put in a left rudder about as the flight
18 test data showed later, about 6 or 7 degrees of rudder,
19 and then I let the airplane -- and then saw what the
20 roll rate was. And passing a 60 degree angle of bank,
21 rolling through 60 degrees angle of bank, I took out
22 the rudder peddle and recovered the airplane.

1 MR. CLARK: When you were putting in the
2 rudder peddle, what kind of aileron controls were you
3 putting up?

4 THE WITNESS: I still had enough aileron to
5 maintain that roll rate, which is about 30 degrees of
6 aileron.

7 MR. CLARK: So maintained a constant wheel
8 position and then put in the rudder, --

9 THE WITNESS: Yes.

10 MR. CLARK: -- maintaining the constant wheel
11 position?

12 THE WITNESS: Yes.

13 CHAIRMAN HALL: When you say put in the
14 rudder, that's putting your foot on the peddle?

15 THE WITNESS: Yes.

16 CHAIRMAN HALL: And then when you say taking
17 it out, is that taking your foot off the peddle?

18 THE WITNESS: Yes. Putting it in -- yes,
19 that's correct. Putting it in means I put a rudder
20 input in and I tried to put it in at a specific rate
21 and I tried to go to a specific end value and then hold
22 it there for a time period just so we could get the

1 data and see what it looked like. And then took it
2 back out.

3 I didn't step on the opposite rudder. I
4 allowed the rudders to go back to neutral and then I
5 rolled the airplane back to wings level and then pulled
6 the nose up.

7 CHAIRMAN HALL: Sorry, John.

8 MR. CLARK: That's all right.

9 As you were rolling the airplane into this
10 test, what kind of G rate were you commanding?

11 THE WITNESS: One.

12 MR. CLARK: And what kind of speed excursions
13 did you experience?

14 THE WITNESS: Once the airplane rolled, since
15 I didn't purposely keep the nose up, the airspeed built
16 up. So during the maneuver, actually retracted the
17 flaps from 1 to up because there's 230 knot restriction
18 on the airplane. At no point in time during the flight
19 test did I exceed any of the airplane flight manual
20 limitations. But we ended up at 230-235 knots.

21 We also ended up at about 90 degrees left
22 wing down and 30 degrees nose low.

1 MR. CLARK: And 30 degrees on the pitch?

2 THE WITNESS: Yes. We also performed steady
3 heading slide slips, and --

4 MR. CLARK: Let me go back for just a second.
5 How much altitude did you lose in those maneuvers?

6 THE WITNESS: Since I was limited two G's,
7 maximum of two G's on the recovery and I didn't want
8 normal roll rates, I lost about 2,500 feet.

9 MR. CLARK: How many of these types of tests
10 did you perform?

11 THE WITNESS: We did one series of them;
12 seven to 10.

13 MR. CLARK: And you have the FDR data on all
14 of that?

15 THE WITNESS: Yes.

16 CHAIRMAN HALL: Were these tests performed as
17 part of the party work or were these tests
18 independently performed by Boeing?

19 THE WITNESS: The tests were performed by
20 Boeing under an engineering work authorization to try
21 to help verify the simulator database that we were
22 using for the M-cab for the performance group to use.

1 MR. CLARK: Okay. You were going to describe
2 a steady heading side slip?

3 THE WITNESS: Oh, we also did -- on those
4 tests, not only did we just look at the roll rates. We
5 looked at steady heading side slips, so we had -- like
6 I said, there was a 737-300 airplane and we went to
7 flaps 1 and 190, and again looked at steady heading
8 side slips, the ability to stop the roll and the
9 controllability of airplane, and found out that it
10 matched fairly well in the simulator at 190 knots.

11 It takes about 70 percent of the wheel
12 authority once you get stabilized and then if you
13 control the airplane in pitch to slow the airplane
14 down, at about 170 knots it's a tie where the aileron
15 and the rudders match. And then at 210 knots or so,
16 it's about 40 to 50 percent of the wheel to counteract
17 the full rudder.

18 MR. CLARK: Were any of those tests conducted
19 in a dynamic manner?

20 THE WITNESS: No.

21 MR. CLARK: You answered Mr. Purvis'
22 questions on the rudder rate tests that were conducted

1 in the simulator, in which I believe you stated that
2 for all the rudder rates, all of these events were
3 recoverable.

4 I guess my question is are you aware of any
5 dynamic type testing that's being done to validate the
6 simulator in that flight regime out to those extremes?

7 CHAIRMAN HALL: John, could one of you all
8 explain what you mean by a dynamic test?

9 THE WITNESS: You want me -- dynamic testing,
10 when they do the -- the classic stability control says
11 you'll go out and do a steady heading side slip, as Mr.
12 Berven explained. When you do a steady heading side
13 slip you're looking for a couple of different factors:
14 One, you're trying to prove that the airplane has
15 positive directional stability, i.e., the nose of the
16 airplane always wants to go into the wind. And it's
17 linear, so you can test that by stepping on the rudder
18 peddle input and that causes a rolling moment and that
19 rolling moment is counteracted by the ailerons.

20 It also causes a side force moment because
21 you actually have wind blowing against the side of the
22 fuselage, and that's counteracted by the bank angle.

1 So, you can check the linearity. You can
2 check the values of how the airplane flies by
3 constantly increasing these parameters and checking to
4 make sure that you have to constantly increase the
5 aileron, the lateral flight control against it, and
6 that your bank angle constantly increases.

7 And when you go to the limit of the control
8 authority and you can check these lines and they don't
9 reverse, it doesn't take less bank angle at a higher
10 rudder, that the rudder doesn't have a tendency to go
11 to an uncommanded position in these flight tests. And
12 that's a static stability case.

13 A dynamic stability case is where you
14 literally just go up and stomp on the rudder peddle.
15 In that case the inertia terms of the airplane have a
16 big effect. Get this mass of metal moving quickly, it
17 has a tendency to overshoot its final commanded
18 position and then it comes back to that commanded
19 position. And at the same time you set up oscillatory
20 modes that are present in airplanes such as the Dutch
21 roll mode.

22 So, if I had just stepped on the left rudder

1 peddle hard, the airplane would have a tendency -- it
2 would yaw and then it would roll. Some of that yaw
3 angle would actually come back out and then go back in
4 and come back out and go back in. And that would be
5 the Dutch roll mode.

6 In the 737, even with the yaw damper not
7 installed, that oscillatory mode always stops. It may
8 take quite a few cycles for it to stop, but it always
9 does dampen out. But it's a more dynamic test.

10 One of the most dynamic tests that you do is
11 engine failure. You can either have an engine failure
12 shut down and just slow down and look at it, or you can
13 just be at the speed that you want to test it for and
14 then just shut it off.

15 CHAIRMAN HALL: Thank you.

16 MR. CLARK: If we don't have the dynamic data
17 to validate the simulator, it is possible that the
18 simulator may be recoverable under these hard rudder
19 inputs, wherein out in the actual world, the airplane
20 won't operate?

21 THE WITNESS: That's a question we don't
22 know. The simulator data we have, as Mr. Kerrigan

1 explained yesterday, is derived from flight test data.
2 We don't have flight test data where you have full
3 rudder peddle inputs in a stalled condition. We just
4 have to use the best wind tunnel data that you have and
5 model that.

6 MR. CLARK: You've flown flight tests in
7 which the airplane is rolling and you put in -- you
8 rolled to the left and put in left rudder and you
9 participated in that simulator work and that backdrive
10 model work where you see the visual cues.

11 In any of your experience in this area have
12 you seen any visual cues or felt any motion cues that
13 would tend to make you put in left rudder peddle as
14 that situation started to develop?

15 THE WITNESS: No.

16 MR. CLARK: From your experience in the
17 simulation work and your wake turbulence encounters,
18 would you expect a 737 to be upset by the wake of a 727
19 at four miles?

20 THE WITNESS: In the cases that we had there
21 with the clear turbulence and what I know of vortexes
22 and if you were flying up, you kind of flew up into it,

1 yes. I'd expect it to roll the airplane in the 20
2 degree bank range.

3 MR. CLARK: And one point I believe -- and
4 correct me if I'm wrong. You said that in some of the
5 turbulence encounters you saw up to 50 degrees bank
6 angle. And in that, would you describe the wheel
7 responses or the pilot corrective action? Were they
8 delayed or where they --

9 THE WITNESS: No. These were -- none
10 whatsoever.

11 MR. CLARK: So you were seeing 50 degrees
12 without any response from the pilot?

13 THE WITNESS: That's correct.

14 MR. CLARK: And so that number would be less
15 if a pilot took timely action?

16 THE WITNESS: Yes.

17 MR. CLARK: And in one case I believe it was
18 answered, but in the case where you have seen data up
19 to 80 seconds, that was strictly behind the 747 and
20 whatever, a time delay of 60 seconds?

21 THE WITNESS: Yes.

22 MR. CLARK: That was not --

1 THE WITNESS: That was a specific test
2 looking for wake. I mean, they purposely flew the
3 airplane into the event. Eighty degrees may be a bit
4 high. It's a very dramatic videotape to watch.

5 MR. CLARK: Okay. But in that situation,
6 that's not consistent with the scenario that we believe
7 is going on?

8 THE WITNESS: No. It's a much higher wing
9 lowering airplane. It has a lot higher vortex
10 capability, a lot closer, and also disperses into the
11 ground, which the effects breaks it up, does different
12 things.

13 MR. CLARK: Okay. Thank you.

14 I have no further questions.

15 CHAIRMAN HALL: Mr. Schleeede?

16 MR. SCHLEEDE: Yes. Regarding the testimony
17 about these flight tests where you were matching the
18 circumstances of flight 427, when was that done, the
19 time frame?

20 THE WITNESS: The simulator studies, or --

21 MR. SCHLEEDE: No. The ones you were doing
22 in the airplane.

1 THE WITNESS: The first part of October.

2 MR. SCHLEEDE: Is that test plan or the rests
3 of that, is that in our record? Is it in the record
4 for the hearing?

5 THE WITNESS: I don't know. I'd have to ask
6 our Group Chairman that. I haven't read all the inputs
7 that Boeing has.

8 MR. SCHLEEDE: Was the data reduced and
9 plotted from these flights?

10 THE WITNESS: Yes.

11 MR. SCHLEEDE: Thank you.

12 That's all I have.

13 CHAIRMAN HALL: No questions, Mr. Laynor?

14 (No response.)

15 Just one or two questions, Mr. Carriker.

16 John, Mr. Purvis, you have a comment?

17 MR. PURVIS: May I put another question to
18 him?

19 MR. PURVIS: You're not timely, but yes, you
20 may.

21 MR. PURVIS: Sorry.

22 Mr. Carriker, have you flown the 737-300 with

1 the yaw damper at a hardover condition, say the full
2 three degree authority? And if so, what's your
3 experience?

4 THE WITNESS: Yes. You can simulate a yaw
5 damper hardover. You don't have to inject the fault.
6 You can just trim the airplane -- trim the rudder to
7 three degrees over, keep the rudder squared away with
8 your feet, and then take your feet off. That simulates
9 a yaw damper hardover.

10 The airplane oscillates left and right as the
11 Dutch roll dampens out. Turn the yaw damper off so it
12 doesn't work, and then put this in. And then the
13 autopilot handles it within 15 to 20 degrees of bank
14 and it stops.

15 It depends on the flight condition. If you
16 do it at very high speeds it's more dramatic. If you
17 do it at very low speeds it's not very much.

18 MR. PURVIS: Would you characterize it as
19 controllable?

20 THE WITNESS: Oh, yes, by the autopilot. If
21 you don't do anything, the autopilot will cancel it
22 right out.

1 MR. PURVIS: Okay. Thank you.

2 CHAIRMAN HALL: Mr. Carriker and
3 representatives of Boeing -- gentlemen, if those
4 results of that test are not presently part of the
5 record, I would appreciate it if they could be
6 submitted since they were discussed at this hearing,
7 and could be made a part of the public record.

8 Mr. Carriker, you mentioned that you were one
9 of the individuals that participated in the simulation
10 where we used a portion of the cockpit voice recorder
11 tape in the simulator. And were you able to learn
12 anything else in addition concerning the accident
13 flight after that simulation with the cockpit voice
14 recorder than before?

15 THE WITNESS: No. As a group of 16 people
16 that sat through simulations, we didn't identify any
17 extra noises. Myself, as being a member of the CVR
18 team, I had another chance to listen in and try to
19 associate some of the noises with what I thought was
20 going on in the airplane. But no, there was no
21 identification of any of the thumps that resulted from
22 this test.

1 CHAIRMAN HALL: So we still don't have a
2 clear idea or know -- well, we weren't able to identify
3 some of the sounds that are on the tape?

4 THE WITNESS: No. We had lots of ideas but
5 everybody had ideas of what it could be but nobody
6 said, "I know that it's this."

7 CHAIRMAN HALL: My experience in traveling
8 around is there's a lot of use now in terms of trip or
9 traveling purposes, of video cameras in cockpits. Does
10 Boeing use that routinely with your simulators?

11 THE WITNESS: Not in the simulators.
12 Actually, in flight tests we put video cameras in the
13 cockpit. We do it to record the displays. We still
14 have digital data taken for flight control positions
15 for such things as that. But we use video cameras for
16 all the displays in the cockpit now that we have --
17 through our ICAST systems where you get messages
18 written up and they don't have any noise or anything
19 like that. Then we record those kind of things on a
20 video. We constantly record it on a video camera.

21 CHAIRMAN HALL: How costly do you think -- I
22 guess you're a unique person in that you are both the

1 pilot that's flown it and you also help program the
2 simulator.

3 THE WITNESS: No. I don't help program the
4 simulator.

5 CHAIRMAN HALL: You don't program the
6 simulator?

7 THE WITNESS: No.

8 CHAIRMAN HALL: How does that -- how do you
9 get that information then? You mentioned your flight
10 test and they use that to program the simulator?

11 THE WITNESS: The stability and control
12 people, they know the coefficients that cause the
13 airplane -- the coefficient -- the power, how much
14 power the aileron has, how much power the rudder has,
15 things like this, and the results of it. So when you
16 go out and you put in a known input in and then you get
17 the known output, they can go back to the simulator,
18 put that same input in and then run it through the
19 computer and see that the answer that's kicked out by
20 the computer matches the answer that was kicked out on
21 the flight test.

22 And if it doesn't, then they go back in and

1 make it come up with the same solution by various
2 modifications. Make sure that what the inputs that we
3 put in the simulator match what flight test said come
4 out when we did the exact same thing in the airplane.

5 CHAIRMAN HALL: How much time have you spent
6 on this accident?

7 THE WITNESS: Hundreds of hours.

8 CHAIRMAN HALL: Mr. Carriker, -- are there
9 any other questions for this witness?

10 Mr. Clark has one more question.

11 MR. CLARK: I believe there's going to be
12 some discussion later on hydraulic systems, but to your
13 knowledge are Boeing pilots or 737 pilots trained to
14 disable the hydraulic system in response to flight
15 control malfunction failures?

16 THE WITNESS: Yes. All the time that you
17 shut off the flight controls or to turn off the
18 hydraulic system, it's called for in the checklist.
19 So, I mean, we don't -- we do in our production checks
20 but that's for different reasons. But on a normal line
21 flight, any time that you shut off the flight control
22 system -- and we do have the ability to shut off the

1 two flight control systems with a switch in the cockpit
2 -- you only do it when it's called for by the checklist
3 because you've had a failure.

4 MR. CLARK: But typically in that response
5 that's a checklist item, or --

6 THE WITNESS: That's correct.

7 MR. CLARK: -- an emergency response item?

8 THE WITNESS: That's correct.

9 MR. CLARK: Thank you.

10 CHAIRMAN HALL: Mr. Carriker, thank you very
11 much for your time and you are excused at this point.

12 (Witness excused.)

13 CHAIRMAN HALL: The time that the Chairman
14 sees on his watch is 11:55 and I would assume that
15 would be an appropriate time for this hearing to take a
16 lunch break and to reconvene at 1:00 p.m. sharp.

17 (Whereupon, the luncheon recess was taken at
18 11:55 a.m.)

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AFTERNOON SESSION

[Time noted: 1:00 p.m.]

CHAIRMAN HALL: Call our hearing back to order and ask for Mr. Harry Dellicker to please come forward.

He is a Flight Data Recorder Data Analysis/Simulation Expert with the Boeing Commercial Airplane Group out of Seattle, Washington.

(Witness testimony continues on the next page.)

1

2

1 HARRY DELLICKER, FDR DATA ANALYSIS/SIMULATION EXPERT,
2 BOEING COMMERCIAL AIRPLANE GROUP, SEATTLE,
3 WASHINGTON

4
5 (Whereupon,

6 HARRY DELLICKER,
7 was called as a witness by and on behalf of NTSB, and,
8 after having been duly sworn, was examined and
9 testified on his oath as follows:

10 CHAIRMAN HALL: Mr. Dellicker, welcome.

11 Mr. Schleede will begin the questioning.

12 MR. SCHLEEDE: Please give us your full name
13 and business address for the record?

14 THE WITNESS: It's Harry Dellicker, and I
15 work with Boeing Company, P.O. Box 3707, Seattle,
16 Washington.

17 MR. SCHLEEDE: What is your position with
18 Boeing?

19 THE WITNESS: I'm an engineer in the
20 Aerodynamics Group, Renton Aerodynamics.

21 MR. SCHLEEDE: Could you give us a brief
22 description of your background and education?

1 CHAIRMAN HALL: We've begun the hearing and
2 if you have to have conversations, please conduct them
3 outside. We need to have the room quiet so that those
4 that want to listen will have the opportunity to do so.

5 Thank you.

6 MR. SCHLEEDE: Go ahead.

7 THE WITNESS: I've been with the company for
8 17 years and I have worked for 12 years developing
9 tools and methodologies for analyzing flight test data.

10 MR. SCHLEEDE: Do you hold any FM ratings or
11 certificates?

12 THE WITNESS: No.

13 MR. SCHLEEDE: Thank you. Mr. Jacky will
14 proceed.

15 MR. JACKY: Thank you.

16 Good afternoon, Mr. Dellicker.

17 Could you please describe for us your
18 participation in the investigation of USAir 427?

19 THE WITNESS: Certainly. I got involved
20 shortly after the accident. Because of my expertise in
21 dealing with flight test data, it was felt that we
22 might be able to add some additional information in

1 terms of understanding the airplane's motion.

2 Normally we work with flight test data and
3 use these tools to compare data channels against one
4 another to check for accuracy and to basically fill in
5 missing pieces.

6 MR. JACKY: And what types of tools are you
7 referring to in your study of flight test data?

8 THE WITNESS: This is what we would refer to
9 as a kinematic analysis and the study of kinematics is
10 a branch of dynamics that deals with aspects of motion,
11 acceleration rate, position of a vehicle body of any
12 type without regard to force or mass. So it doesn't
13 matter what is acting on the body. You can use the
14 equations of motion to use to relate one aspect of
15 motion to another.

16 MR. JACKY: Can you give us a simple example
17 of what kinematics or the study of kinematics might
18 produce?

19 THE WITNESS: Yes. A good example would be a
20 vehicle, an automobile traveling straight down the road
21 along a straight line. Given a history recording of
22 the speed of that vehicle as it's accelerating or

1 decelerating, I can tell you how far the vehicle has
2 traveled in any given period of time. I can also
3 generate for you a history of the acceleration or
4 deceleration of that vehicle. Again, starting only
5 with the knowledge of the speed.

6 So you can fill in these two missing pieces
7 and then, taking that a step further, assuming that the
8 vehicle is traveling on a level road, if I know the
9 mass or weight of the vehicle, I can give you a good
10 estimate of the force that was acting on it to produce
11 the calculated accelerations.

12 And that's a -- I should say that's a simple
13 one degree of freedom program. Again, you're just
14 traveling along a straight line down the road. In the
15 case of an aircraft, we have six degrees of freedom,
16 and that's basically velocity along the X axis parallel
17 to the body, the fuselage, and also a roll about that X
18 axis where the wings dip to one side or the other.

19 You also have velocity along the Y axis which
20 goes out to the wings. That's the sideways motion and
21 a pitch about that axis. And then velocity in the
22 vertical direction along the Z axis and a yaw about

1 that axis.

2 And the equations are much more complex that
3 relate all of those together than in the one degree of
4 freedom case, but the basic principle is the same.

5 MR. JACKY: Earlier, Mr. Kerrigan testified
6 as to a backdrive simulation, a match of the flight
7 data recorder information from USAir 427. Could you
8 describe for us what the differences are between the
9 backdrive simulation and the kinematic study which you
10 performed?

11 THE WITNESS: Sure. Basically, using the
12 simulation and doing a backdrive, you're trying to
13 solve simultaneously for two sets of unknowns, both the
14 unknown aspects of the airplane motion and for the
15 forces that produce that motion.

16 Now, this is done basically by iteratively
17 trying to predict forces acting on the airplane. You
18 run the simulation through this match of the accident
19 scenario and try to match the known aspects of the
20 airplane motion that were recorded on the flight data
21 recorder. And generally this is done with what we call
22 a math pilot. So the real trial and error, if you

1 will, is in developing the control laws and the gains
2 in that math pilot that allow the simulation to match
3 the airplane motion.

4 What makes it challenging is that the forces
5 that you're trying to estimate and the unknown aircraft
6 motion that you're trying to determine out of this are
7 mutually dependent on one another. One will change the
8 other. And you can get there with a simulation.
9 Actually, the simulation is an excellent tool and we
10 use it all the time. But in some cases it can take
11 quite a while to get to the desired target.

12 In the case of the kinematic analysis, we
13 uncouple the problem, so to speak. We break it down
14 into two major parts. In the first case, we're solving
15 for the aircraft motion, again, without regard to the
16 forces that were acting on it. In this case we're
17 starting with -- from USAir 427 we have seven motion
18 variables. We have the three oiler angles, pitch, yaw
19 or heading and roll, and we have the acceleration along
20 the X axis of the body in this direction, acceleration
21 vertically, the airplane speed and the airplane
22 altitude.

1 And using the kinematic equations of motion
2 we can work with that data and estimate the major
3 unknowns, those being the angle of attack of the
4 aircraft, which is the angle between the body axis of
5 the aircraft and the air. So if he's flying along
6 downward, we're talking about this angle here. The
7 other angle being the side slip, which you could think
8 of as you're driving on an ice road, you go into a
9 corner and you turn left. The car starts sliding right
10 and that's positive side slope. So it basically kind
11 of skid into the turn.

12 That process in this case is a special
13 adaptation of what we normally do in flight tests.
14 Normally in flight tests we had some direct indications
15 of the size of the angle. We have lateral
16 acceleration, acceleration sideways. And in fact, we
17 normally record a pressure differential across the
18 nose of the aircraft that we can relate directly to the
19 side slope.

20 In this case, the side slope actually becomes
21 the major unknown and really the one variable that we
22 have to deal with in this analysis. And the process is

1 iterative.

2 We started out assuming, because we had no
3 better information, we assumed that the side slip was
4 zero. And the first time through -- let's put the
5 chart --

6 MR. JACKY: You're referring to Exhibit 13-G,
7 I believe?

8 THE WITNESS: Yes. Exhibit 13-G, page 17.
9 It's also Figure A-1. It's about a third of the way
10 through Exhibit 13.

11 VOICE: What page number?

12 THE WITNESS: Through page 17.

13 Thank you.

14 Now, this is a rather busy plot. What this
15 shows is the effect of the assumed side slip angle on
16 our predicted speed and angle of attack. I'm sorry.
17 Not angle of attack but altitude. Angle of attack is
18 not shown.

19 Basically, the analysis proceeds starting
20 with a zero side slip angle and when we went through
21 it, it produced speeds and altitudes that were greatly
22 in disagreement with the flight data recorder. Speed

1 at impact was about 100 knots higher than recorded and
2 impact in fact occurs about four seconds before it
3 actually happened, according to the FDR.

4 So, went into a process here. I can
5 iteratively -- basically, make a guess on side slip
6 using the simulator as a guide and honing in on the
7 side slip angle that would give us a good match on
8 these parameters, as well as the angle of attack, which
9 I don't show here. But that match is based on the
10 predicted stall warning with the final, what I'm
11 calling side slip, which is this second curve from the
12 top, we matched the stall warning onset within about a
13 half a second. We're matching the speeds all the way
14 through within about 10 knots following the upset, and
15 we match the altitude very, very closely here, showing
16 impact just after 160 seconds.

17 The real reason for this particular curve or
18 the plot was to show the sensitivity of these various
19 parameters to the side slip, just as an indication of
20 how powerful these measurements were as a guide in
21 arriving at the estimate that we have.

22 MR. JACKY: And so if I follow you correctly,

1 you are making an estimation of the side slip angle of
2 the aircraft over time and then using that information
3 to backdrive the simulator to see if the altitude,
4 airspeed and angle of attack data match the other FDR
5 parameters?

6 THE WITNESS: Well, we also did that step
7 taking this information and backdriving the simulator
8 as a second check. But my work primarily was
9 independent in the early stages and we were just
10 comparing these results directly with the flight data
11 recorder, what information we had.

12 Having then defined the airplane motion as
13 best we could, we proceed into the second stage where
14 we solve for the forces and moments acting on the
15 aircraft using the assumed weight and inertias through
16 estimates provided by the NTSB.

17 Actually, let me back up. I intended to show
18 the match that we arrived at on airspeed and altitude.
19 Let's go to page 20.

20 The three curves on this plot, the solid line
21 represents the raw flight data recorder data, adjusted
22 going for barometric pressure, so this is as the pilot

1 would have seen it on his instrument.

2 The short dashed line represents that data
3 corrected with a nominal position air correction that
4 we have, that we've developed from flight tests, which
5 accounts for the effects of angle of attack and side
6 slope on the airspeed instrumentation.

7 And the long dashed line represents the final
8 kinematic analysis which is a little bit on the low
9 side, but the impact is at the right point in time, as
10 far as we can tell.

11 The remaining difference between those bottom
12 two curves is probably due to some remaining
13 uncertainty in just what the position air correction
14 would be, because we don't have flight test data all
15 the way out into that regime of angle attack and side
16 slope. It's an extrapolation of our data.

17 And on page 21, this is similar to the
18 altitude comparison. The solid line is the raw flight
19 data recorder information. The short dashed line is
20 that data corrected with out nominal position air
21 corrections and the long dashed line is the
22 kinematically derived airspeed which is within 10 knots

1 -- normally closer.

2 During the initial phase prior to the upset,
3 the match is essentially exact. It says within a knot
4 everywhere. Which also indicates the low magnitude of
5 the winds, by the way.

6 MR. JACKY: How far back did you go back in
7 the data prior to the upset in order to match the data?

8 THE WITNESS: I started the match all the way
9 from time zero to the full 132 seconds up to the upset
10 and then from there on. The initial part of the data
11 is used in helping to calibrate the acceleration data.
12 And then once that's calibrated, you use that through
13 the remainder of the upset to define the airplane
14 motion.

15 That basically completes the kinematic part
16 of the analysis. From there we move into the
17 coefficient, the force analysis, where we're trying to
18 estimate the forces and moments acting on the aircraft.

19 MR. JACKY: And how would you accomplish
20 that?

21 THE WITNESS: That's done as in the earlier
22 example of the automobile. You use the aircraft weight

1 and inertia information and then the X, Y and Z
2 directions. The forces associated with those are
3 determined from the simple equation: force equals mass
4 times acceleration. The accelerates we've determined.
5 The mass we have from data. The force is a direct
6 calculation. And similar calculations for the moments
7 which cause the yaw, pitch and roll.

8 That represents the total forces and moments
9 acting on the airplane. At the same time, we can
10 basically predict from the simulator model the total
11 forces and moments that we would achieve at those
12 flight conditions. At each point in time the airplane
13 is at a certain angle of attack. The side slope, we're
14 assuming failed controls because we don't have that
15 data. So we add up basically all the parts of the
16 simulation model that we know and that gives us a total
17 for the simulator model.

18 We then take the difference between that set
19 of forces and moments versus what we calculated for the
20 airplane and that represents a set of force and moment
21 increments that we need to add to the simulation to
22 make it match the estimated aircraft motion.

1 We can then relate those incremental forces
2 and moments to things such as -- well, I'll back up.
3 Those represent the combined effects of all the unknown
4 external forces acting on the aircraft; things such as
5 forces due to deflected controls, forces due to the
6 wake encounter, unknown winds aloft, possible
7 structural damage, if there were any. And it also
8 reflects any errors that may still remain in the
9 estimate of the aircraft motion.

10 A kinematic analysis is certainly not
11 perfect, but it's very close.

12 MR. JACKY: So in other words, you have the
13 amount of force difference that you have no way to
14 account for and need to account for? Is that a correct
15 way of saying that?

16 THE WITNESS: I'm sorry. Repeat that?

17 MR. JACKY: Well, you say you end up with an
18 incremental amount of forces, I would assume, in each
19 axis that you now would in some way need to account
20 for?

21 THE WITNESS: Right. Yes.

22 MR. JACKY: And how would you go about doing

1 that?

2 THE WITNESS: Why don't we start by going
3 back to page 6. Let's start out by showing the actual
4 raw aerodynamic coefficient data that was derived from
5 the analysis. And what we have here on the first curve
6 is actually the side slip angle and the second curve
7 down is the total unknown yawing moment, the combined
8 effects of the wake, possible rudder and anything else
9 that may have been happening to the airplane that
10 produce the yawing moment.

11 And the bottom curve is the rolling moment
12 with similar explanation, again, due to wake activity,
13 wheel possibly.

14 MR. JACKY: So this is the amount of moment
15 coefficient that you're left over with?

16 THE WITNESS: That's right. After we've
17 accounted for the side slip and everything that we
18 know, this is what's left over. So this represents,
19 again, the effects of the wake and controls and
20 anything else that's not known.

21 MR. JACKY: And then the side slip angle at
22 the top of the page would represent your best guess of

1 what the estimated side slip would be?

2 THE WITNESS: Yes. That is right. And it
3 showed on that little plot, if you change that side
4 slip very much you get some serious disagreements
5 between this analysis and the recorded data. Every 25
6 percent change in side slop produces about a 25 knot
7 error in airspeed and about a 400 foot error in
8 altitude. So we believe this is fairly close.

9 The next step would be to take these data and
10 convert those to equivalent control positions or trim-
11 out yawing moment with rudder and rolling moment with
12 wheel. And this is done in such a way that when we put
13 in the rudder to compensate for the yawing moment, that
14 rudder also produces a roll and other coefficients
15 which are fed back into the analysis. And then that
16 would affect the wheel to trim.

17 Likewise, when you put in wheel to trim in
18 the rolling moment, that affects the rudder.

19 If you look at page 8, this is basically the
20 same as the previous plot except, as I say, we've
21 converted the yawing moment to equivalent rudder and
22 rolling moment to wheel. And in addition, we've shown

1 the predicted blowdown angle for the rudder for
2 comparison purposes.

3 In this case, we show a fairly close
4 correlation in the levels between the predicted rudder
5 and the blowdown angle up to the point where the
6 airplane rolled over. Beyond that point, this would
7 suggest that more rudder is required than what can be
8 produced when you get beyond the blowdown angle.

9 The rolling moment in this case has been
10 converted, as I say, into wheel. And it's trimmed
11 throughout the entire time history, which means it's
12 done as if it had actually been flown this way. So at
13 the point where it rolls over, it would assume that the
14 pilot put in wheel to do that, which is probably not
15 realistic.

16 If you go to page 11, the difference in this
17 plot is that we assumed that from 145 seconds on, the
18 wheel was maintained at its maximum positive effective
19 position of plus 85 degrees.

20 MR. JACKY: Which direction would that wheel
21 input be?

22 THE WITNESS: Pardon me?

1 MR. JACKY: Which direction is positive
2 wheel?

3 THE WITNESS: That's right wing down, so
4 countering the roll. So it assumes that the wheel is
5 maintained in that direction. And the difference in
6 the yawing moment that that produces in the lateral
7 control is then reflected into the rudder. As you can
8 see, it brings down the predicted effective rudder,
9 equivalent rudder, to be fairly close to the predicted
10 blowdown.

11 What is still missing in this analysis and
12 something that we need to do as a follow up is to
13 determine what is happening here in terms of both the
14 rolling moment and yawing moment. If in fact the wheel
15 that I showed, the effective wheel that I show here
16 represents the wheel as it actually was input, then
17 there's a substantial negative rolling moment that's
18 now unaccounted for, the rolling moment that actually
19 rolled the airplane over in spite of having in positive
20 wheel.

21 And corresponding to that would be very
22 likely a fairly strong yawing moment, if this is due to

1 some sort of stall condition of the wing which has
2 occurred because of the increasing angle of attack. It
3 goes through stickshaker at the point where the
4 airplane rolls over and by my analysis it continues up
5 into about the 24-25 degree angle of attack range. In
6 that region, we may be getting some type of asymmetric
7 wing stall and we have not predicted the yawing moment
8 associated with that.

9 MR. JACKY: Do you have angle of attack
10 plotted here now?

11 THE WITNESS: Yes. If we go to -- probably
12 page 2. I don't have that page. Oh, yes, I do. Hold
13 on.

14 (Pause.)

15 Sorry. Page 5. Yes. Thank you.

16 Angle of attack is the second curve from the
17 top. Just below that is the indication of stall
18 warning, which -- that's my predicted stall warning
19 which is going off at 144.5 seconds. And as I say, the
20 wing angle of attack continues on up into the --
21 oscillates between about 20 and 26 degrees.

22 MR. JACKY: You mentioned stickshaker. Have

1 you tried correlating the moment of stickshaker onset
2 by your analysis to the timing that was shown on the
3 CVR?

4 THE WITNESS: According to the current
5 analysis of the CVR, this stickshaker is sounding
6 roughly a half a second before it did on the tape. If
7 I take the difference in time between when the engines
8 started to spool up -- to accelerate, and the
9 stickshaker sounded, if I apply that to the FDR data,
10 because we have the N-1, engine RMP in the FDR data,
11 then that would place the stickshaker event much closer
12 to what I have here, within about two-tenths of a
13 second.

14 In fact, the original time given by the NTSB
15 was 144.7 seconds for the stickshaker and that's pretty
16 close, just based on that incremental approach.

17 MR. JACKY: If I could refer you back to page
18 Number 6 of Exhibit 13-G.

19 THE WITNESS: Okay.

20 MR. JACKY: In looking at the calculated
21 yawing moment coefficient increment, do you know of any
22 control surface or any other part of the airplane that

1 might give you that type of yawing moment?

2 THE WITNESS: At this point, no. We have
3 done some testing in the wind tunnel, as you're aware,
4 of the modeling slat damage of the number 1 slat.
5 Actually, I have not looked at the results of that. I
6 don't believe that it produces that much, but I'm not
7 certain of that.

8 We're talking a very substantial yawing
9 moment.

10 MR. JACKY: So unless there is some sort of
11 failure mode identified on the airplane, the best fit
12 of that increment would be served by a rudder input?

13 THE WITNESS: That's how we've chosen to show
14 it. It certainly looks consistent with that. We do
15 need to look further. We have not closed out the issue
16 of the slat and I think that still has to be open to
17 consideration.

18 MR. JACKY: Now, if I can turn your attention
19 to page 11 of your --

20 CHAIRMAN HALL: Let me just clarify if I
21 could for my own understanding here. This one yawing
22 moment, you don't feel like you still have the answer

1 for? You're still going to continue to do research and
2 additions for it?

3 THE WITNESS: I intend to continue looking at
4 this. There's -- especially in the initial onset of
5 this upset, there is the question of the wake and we
6 are working on trying to improve our modeling of that
7 to determine how much of the roll and yawing moment may
8 be due to the wake and see what's left over that can be
9 attributed to the controls or whatever else was
10 involved.

11 CHAIRMAN HALL: How long has it taken you up
12 to this point? When did you start this work?

13 THE WITNESS: I started this September 23rd.
14 I've put probably between 600-700 hours into this so
15 far.

16 CHAIRMAN HALL: Thank you.

17 I'm sorry, Tom. Go ahead.

18 MR. JACKY: Thank you, Mr. Chairman.

19 The equivalent rudder angle that we show on
20 the chart on page number 11, to me the line shows a
21 certain amount of -- excuse me -- a jaggedness, or it
22 doesn't seem to be a smooth line. Would you expect it

1 to be smoother?

2 THE WITNESS: We're talking about the
3 equivalent rudder now?

4 MR. JACKY: The equivalent rudder. Yes.

5 THE WITNESS: Yes. Most of that noise is
6 related to the -- most likely the sample rate of the
7 data, which in general is quite low. The maximum
8 sample rate that we have available is the vertical
9 acceleration and that was a sample. The second other
10 parameters which more directly affect this, such as
11 heading angle, are only one sample a second. And that
12 tends to produce a lot of artificial noise in the data.

13 I could have filtered that out. I chose to
14 leave it in here for the time being, just show it as it
15 is. But that's something we could work on.

16 MR. JACKY: And just for comparison sake,
17 when you're working with flight test data, what sort of
18 sampling rates are you looking at to deal with there?

19 THE WITNESS: Typically, we work with 20
20 samples a second or more. Twenty is generally
21 considered the minimum, although there are some
22 parameters where you can get by with less, but that's

1 our normal.

2 MR. JACKY: And if I can refer you to the
3 equivalent rudder angle again, at approximately time
4 1:35 there seems to be a spike in the rudder position
5 to about 10 degrees and then it comes back down.

6 THE WITNESS: Right.

7 MR. JACKY: Do you have any feel for what may
8 be causing that?

9 THE WITNESS: Our best guess right now, and
10 it's still a guess, is that that's wake induced. There
11 is a spike in the rolling moment, the yawing moment,
12 lift, drag, and even a little bit in the pitch that all
13 occur right at that point in time. And that is, like I
14 say, it's most likely related to the wake.

15 If this were actually a rudder event
16 producing that spike I would not expect to see the
17 related motion in the other data channels. You
18 wouldn't get a big spike in lift and drag and what have
19 you, because those are all accounted for pretty well in
20 the simulator model.

21 So if you put the rudder in, we would compute
22 the lift and drag associated with that and you

1 shouldn't see this showing up. So it's most likely a
2 wake phenomena.

3 MR. JACKY: So if I could perhaps summarize
4 what your conclusions of the kinematic study is that by
5 estimating the side slip angle shown at the top of the
6 chart, you then end up with the equivalent rudder and
7 wheel angles or positions that are shown on the bottom
8 of the chart?

9 THE WITNESS: Yes. That's right. And those
10 angles, both the rudder and the wheel, are fairly
11 strong functions of that side slip angle. And if
12 something were to change the estimate of side slip,
13 that would result in changes also in the rudder and
14 wheel.

15 MR. JACKY: And how confident are you in this
16 data?

17 THE WITNESS: I'm pretty confident based on
18 the overall match against the FDR data. Like I say,
19 we're matching the airspeed and the altitude and
20 stickshaker onset point. We also know that the
21 stickshaker, according to the CVR analysis, the
22 stickshaker remained active from the time that it

1 tripped all the way to impact. And that's pretty well
2 borne out by this analysis. At the very end mine goes
3 intermittent, but that's like the last three-tenths of
4 a second.

5 So up to that point, everything looks pretty
6 good.

7 MR. JACKY: And as your work progresses from
8 this point, what type of things would help you in
9 further refining this dataset?

10 THE WITNESS: Well, certainly lateral
11 acceleration would be very helpful if we had an
12 adequate sample rate. That would give us a much
13 greater degree of confidence in our calculation of Beta
14 -- the side slip angle. I'm sorry.

15 Beyond that, of course, it would be real nice
16 to have rudder angle and remove a lot of guesswork.

17 MR. JACKY: That leads me into my next
18 question. If there were certain parameters or
19 something that could be recorded on the flight data
20 recorder that would help you in your efforts, what type
21 of things might you wish to see or would help you
22 directly with this effort?

1 THE WITNESS: Well, in addition to the
2 lateral acceleration, -- and preferably I'd like to
3 have everything in a little bit higher sample rate --
4 to really answer questions like this I think you'd need
5 to have surface positions, pilot control positions.
6 Ideally, even the forces, peddle forces, wheel forces
7 and what have you, so that you could really nail down
8 whether it was pilot input or otherwise.

9 MR. JACKY: And if there were some sort of
10 video recording in the cockpit, is there any sort -- or
11 can you imagine any sort of information coming from
12 that that might help you in this effort?

13 THE WITNESS: If the camera were properly
14 placed so you could really see what was going on, yes,
15 I'm sure it would have added information in this case.
16 For the kinds of analyses that I do, I'd much rather
17 have the digital data on the FDR and if I had all of
18 those items instrumented and recorded.

19 MR. JACKY: So if anything, it might give you
20 some verification as to wheel position say, or --

21 THE WITNESS: Yes.

22 CHAIRMAN HALL: And just in layman's terms,

1 there are things that you could put in this simulator,
2 parameters, that if you had that information off the
3 flight data recorder, it would help you in your work?
4 In other words, that simulator and your calculations,
5 you could have used additional information?

6 THE WITNESS: As I already mentioned, if we
7 had the lateral acceleration, for instance, I could
8 calculate the side slip angle with a much higher degree
9 of confidence and although that still wouldn't tell us
10 what produced the related yawing moments and rolling
11 moments, at least we would be quite confident in our
12 levels of those.

13 I feel from the overall match that we have a
14 good estimate, but it's still an estimate.

15 MR. JACKY: Thank you, Mr. Dellicker. I have
16 no further questions.

17 CHAIRMAN HALL: Could I see the hands of any
18 of the parties that have questions for this witness?

19 I see Boeing. Anyone else?

20 If not, Boeing Group.

21 MR. MCGREW: Mr. Dellicker, just a couple of
22 questions.

1 How would you relate the quality and the
2 accuracy of this analysis versus those reconstructions
3 that Boeing has carried out in past years?

4 THE WITNESS: I believe that this is much
5 higher quality, largely owing to the higher quality
6 data available from the airplane and the additional
7 data. This is I think the first time we've had this
8 many parameters available. Well, maybe not the first
9 time. The first time I've been involved, anyway, and
10 we've had this many parameters available to us.

11 In other accidents where we're dealing with
12 the directional gyros and such, once you get upset past
13 a certain pitch angle and roll angle, you can't rely on
14 the heading angle from those instruments, and that
15 would make this analysis very difficult.

16 MR. MCGREW: One other question. In the
17 event that a video recording were available from the
18 cockpit, would not the instruments or the readings of
19 the instruments as the event progressed be of great
20 benefit?

21 THE WITNESS: I'm trying to think what
22 additional information would be available there that we

1 don't have recorded. Certainly what's going on with
2 the pilot controls, if anything, would be very
3 beneficial. We have airspeed, altitude, all those
4 recorded on the FDR.

5 MR. MCGREW: Thank you.

6 I have no further questions, Mr. Chairman.

7 CHAIRMAN HALL: All right.

8 Any other parties have any questions?

9 (No response.)

10 If not, Mr. Marx.

11 MR. MARX: I just have a quick questions.

12 I'm getting very confused about the degree of
13 rudder change that occurs and the speed of its change.
14 In the last example where you were talking about -- and
15 this would be Exhibit 13-G, page number 8. And you
16 talk about equivalent rudder angle. As it goes from
17 its first spike of the rudder input and after that,
18 that happens at the end of the spike is somewhere
19 around 130 -- what I calculated, about 136-1/2 seconds.

20 And then as you go towards at about 139
21 seconds, you have it reaching a blowdown angle. That's
22 roughly 2 to 2-1/2 seconds, and yet it's going about in

1 the neighborhood of 15 degrees. Is that correct? So
2 it's about 7 to 7-1/2 degrees per second?

3 THE WITNESS: Ah, --

4 MR. MCGREW: Or am I just confused or I have
5 the wrong math there?

6 THE WITNESS: I think that's -- well, let's
7 see.

8 (Pause.)

9 Yes. It could be that high. We had
10 previously estimated up to 6. Another thing I should
11 mention here is that the side slip angle at the top of
12 that page is actually a little bit -- maybe a little
13 too idealized. There is in fact some Dutch roll motion
14 that I know was taking place between 135 and about 141
15 seconds.

16 And the effect of that, if I were to go back
17 into this analysis and account for that, would be to
18 soften that slope with the rudder a little bit. In
19 other words, right at about 136 seconds, the equivalent
20 rudder would go up and at 139 it would go down a little
21 bit so it would tend to round it off. And I haven't
22 had a chance to go back and rerun the analysis with

1 that.

2 MR. MARX: Well, the information we have from
3 Mr. Kerrigan, I guess it was that testified, and I
4 think it was 5 or 6 degrees. Then we had testimony of
5 2-1/2 degrees. Does anybody know for sure what it is?
6 Between 2-1/2 and 8 degrees, maybe more? Does anybody
7 know?

8 THE WITNESS: Actually I'm not certain where
9 the 2-1/2 degree per second number came from. My
10 analysis has been fairly consistent with this level.

11 MR. MARX: A might higher rate is what you're
12 talking about?

13 THE WITNESS: Higher, yes, but certainly not
14 high. I mean, it's nowhere near the rudder capability.

15 MR. MARX: I understand.

16 No further questions.

17 CHAIRMAN HALL: Mr. Clark?

18 MR. CLARK: I'll be referring back to Exhibit
19 13-G, page 8, but first if we could look at 13-G, page
20 18. And if we don't get the viewgraph, don't spend a
21 lot of time. It's a graph called Low Order of Side
22 Slip that shows a side slip rate of about 3 degrees per

1 second.

2 Is that type of a side slip rate consistent
3 with this rudder angle rate of 5 degree per second or 3
4 degree per second?

5 THE WITNESS: Yes. I believe it's quite
6 close. We still need to go back and basically try to
7 bring this analysis together with the simulation
8 analysis.

9 In this analysis, the side slip is actually -
10 - as I say, a variable that I determined to produce a
11 good match in altitude and airspeed. To really
12 validate whether or not that side slip is realistic, we
13 need to bring this match together with the simulator
14 and get to the point where they're both saying exactly
15 the same thing.

16 I believe that it is very close and based on
17 the side slip angles that the simulator is getting at
18 and looking at what's happening to the heading angle,
19 still slight errors in the heading angle on those
20 matches. And if you account for that, it would tend to
21 bring the side slip up close to what I have here.

22 So, yes, I think it is realistic.

1 CHAIRMAN HALL: Mr. Dellicker, if I could at
2 this point just ask you and the gentlemen at the Boeing
3 table -- and first, let me thank you, obviously, for
4 the time that you have put into this work so far. But
5 there has been several references during this hearing
6 to additional work that you all will be conducting that
7 obviously is going to be an important part of this
8 investigation.

9 Do we have any -- can you give us any
10 estimate of time frame on how much longer you think
11 some of these projects that you would like to see done
12 might be completed?

13 THE WITNESS: I believe we're committing to a
14 couple of months, which may be sporting. We'll
15 certainly do our best.

16 CHAIRMAN HALL: Thank you.

17 Excuse me, Mr. Clark.

18 MR. CLARK: I'd like to move back to 13-G,
19 Exhibit 7. These are the coefficients that have been
20 backed out of the match of the data that you've
21 completed?

22 THE WITNESS: That's right.

1 MR. CLARK: Do you see any signatures in this
2 data that would be consistent with a thrust reverser
3 deployment?

4 THE WITNESS: No, I don't. And I did some
5 estimates on that and the amount of differential thrust
6 between the left and right engine associated with a
7 reverser deployment that would be required to generate
8 the yawing moments that we're seeing here would be on
9 the order of 20,000 pounds difference between the two
10 engines. And that would result in a drag coefficient
11 here that would show up as about plus 1600 drag counts,
12 which would be 1-1/2 centimeters positive on this
13 figure. And during the initial upset, the drag tends
14 to be in the negative direction.

15 MR. CLARK: Do you have the laser pen with
16 the pointer?

17 THE WITNESS: I don't know if I do or not.

18 MR. CLARK: If somebody could -- you do?

19 Would you be able to show us on the chart up
20 there the 1-1/2 centimeters you were talking about?

21 And basically, if you move the pencil tip
22 over to where the noise starts on the drag plot.

1 THE WITNESS: On the drag plot about 132
2 seconds right above the drag.

3 MR. CLARK: About right in there. And if you
4 move the pen up --

5 THE WITNESS: Up to 1-1/2 centimeters?

6 MR. CLARK: There we go. If we had a thrust
7 reverse basically, you would expect to see your plot
8 show a signature up in that range rather than what we
9 have?

10 THE WITNESS: Right. And that would be
11 basically sustained throughout the rest of the
12 condition, consistent with this sustained yawing
13 moment.

14 MR. CLARK: As long as the thrust reverser
15 were deployed, if that were the case?

16 THE WITNESS: Right.

17 MR. CLARK: And would you -- what would be
18 your expectations for the lift coefficient?

19 THE WITNESS: I really can't say for sure on
20 that. I'm not sure what the lift interaction would be.
21 I'm not certain.

22 MR. CLARK: Okay. And on the pitching moment?

1 THE WITNESS: I'm not certain on that either
2 because of the wing interactions and the tail and such.
3 I'm not certain which way it would go.

4 MR. CLARK: Conversely or in addition, we've
5 heard theories about various slat deployments and my
6 understanding is that we would have to have a 20,000
7 pound force at the engine pylon area to generate the
8 yawing moments that you saw.

9 What kind of forces would we need for a slat
10 to create that kind of yawing moment?

11 THE WITNESS: It would be probably on the
12 order of two-thirds of that.

13 MR. CLARK: Basically, you're scaling the
14 distance the distance out to the slat to produce the
15 yawing moment?

16 THE WITNESS: Right.

17 MR. CLARK: And then what would you expect to
18 see on the drag plot if we had a slat producing that
19 kind of drag force to create that yawing moment?

20 THE WITNESS: Well, that would scale, too, so
21 it would be --

22 MR. CLARK: Just directly scalable?

1 THE WITNESS: Yes. Approximately. Assuming
2 that it is, yes. Basically, there would have to be a
3 drag force generating that, so yes.

4 MR. CLARK: The first cut or the first
5 estimate would be two-thirds of the 1-1/2 centimeters?

6 THE WITNESS: Just -- yes. A very rough
7 estimate, a half to two-thirds of that.

8 MR. CLARK: And I assume -- or let me ask
9 you. Do you see any evidence of that in your
10 calculations or your data?

11 THE WITNESS: I haven't seen anything that
12 would lead me to believe that it is a slat, but I would
13 hate to rule it out.

14 MR. CLARK: No. I'm not asking you to rule
15 it out. At this point, you don't have an argument to
16 make to me that you see that kind of signature?

17 THE WITNESS: No.

18 MR. CLARK: On Exhibit 13-G, page 8, there is
19 a spike at about 136 seconds on the equivalent rudder
20 angle and I believe you've stated earlier that that in
21 your estimation could be a result of a vortex
22 encounter.

1 THE WITNESS: Yes.

2 MR. CLARK: Based on the sampling rate that
3 we have, it is possible that that spike could be
4 significantly larger than what you've calculated here?

5 THE WITNESS: I don't believe so. The rate
6 of change of heading angle is not all that large. In
7 fact, I did a study in that little narrow region of
8 data where I went in and I interpolated between the
9 existing datapoints with different curve fits with no
10 significant change.

11 I managed to drop that peak by about one
12 degree. It was up around 12-1/2 degrees and I dropped
13 it down a little bit just by very careful comparing of
14 the data between the points. Beyond that, I couldn't
15 justify any further change in that data.

16 MR. CLARK: In that regard, if -- I believe
17 what you're saying if at that point we had no rudder
18 movement that that spike could be generated possibly by
19 the flow field and you're going to continue your work
20 exploring that?

21 THE WITNESS: Yes.

22 MR. CLARK: For that type of spike, that

1 indicates that there are side forces either on the
2 rudder or the horizontal tail. Could the forces that
3 are on that tail producing that spike create -- have
4 the potential to create structural damage either to the
5 vertical tail or the rudder?

6 THE WITNESS: I don't see anything in there
7 that would cause me that concern. And we're only
8 talking about 10 degrees equivalent rudder here. The
9 vertical tail is designed to handle much more than
10 that. I'm not a structure person, but --

11 MR. CLARK: I understand.

12 If we could bring up Exhibit 10-D, page 3,
13 I'd like to ask some questions about that.

14 If we could adjust that slightly so we could
15 have list A in view, and then we'll move to list B.

16 My understanding is that you have very
17 extensive experience in handling flight test data.

18 THE WITNESS: Yes.

19 MR. CLARK: And you've talked earlier about
20 sample rates of at least 20 hertz or 20 datapoints per
21 second.

22 THE WITNESS: Yes.

1 MR. CLARK: Typically on Boeing flight tests,
2 how many parameters do you record or do you capture?

3 THE WITNESS: A grand total, we record
4 literally thousands on the airplane. However, we -- I
5 normally work with on the order of between 50 and 70,
6 in that area. Significant motion parameters, airplane
7 control deflection parameters and so on.

8 MR. CLARK: The list that I've provided to
9 you contains numerous parameters that have been
10 recorded on other flight data recorders. And
11 specifically, the ones that have the checkmarks were
12 recorded on the ATR airplane that recently crashed in
13 Roselawn.

14 would you -- you were describing control
15 parameters, motion parameters that may be recorded.
16 Would you quickly go down through that list and
17 describe to those -- which ones that would seem
18 appropriate or pertinent that you could use in an
19 accident investigation?

20 Let me back up. You talked about what you
21 use in flight test. Now you've completed at least one
22 investigation, and I missed earlier, have you

1 participated in other investigations, accident
2 investigations?

3 THE WITNESS: No. This is my first accident
4 investigation.

5 MR. CLARK: Okay. Then based on your
6 experience here, if you went down that list, could you
7 define to us the parameters that you would like to see
8 be available in some future accident investigation?

9 THE WITNESS: Well, certainly everything that
10 is checked. And, of course, as I said before, it would
11 be very useful to have the actual control surface
12 measurements.

13 MR. CLARK: Thank you. I have no further
14 questions.

15 The only comment I would make is that for
16 information, the airplane we're dealing with in this
17 accident had the recorded parameters on the left-hand
18 side of the column, including the six parameter list
19 and the 11 parameter list. And then also for
20 information, the Colorado Springs airplane had the six
21 parameters list type recorder.

22 But I have no further questions. Thank you.

1 CHAIRMAN HALL: And ATR had all of the items
2 that are checked?

3 THE WITNESS: Yes. That's correct.

4 MR. CLARK: They had additional parameters
5 but for the list that we had, they had at least those.

6 CHAIRMAN HALL: Mr. Schleede?

7 MR. SCHLEEDE: Have you validated these
8 various calculations and the data that you've produced
9 here today by comparing it with the flight test
10 airplane that recorded flight control positions and
11 lateral acceleration?

12 THE WITNESS: Yes. Actually, I did a --
13 basically a two step validation. We validated it
14 against simulator day to begin with to check it all
15 out, and that was based on a simulator match of this
16 condition. And we recorded, as part of that match, all
17 of the motion parameters that we're concerned with,
18 including the size of angle that it produced and angle
19 of attack, and went through, extracted from that
20 dataset just the seven parameters that we had available
21 from 427 and went through this analysis and compared
22 the results against what the simulator had produced for

1 the other motion data and that checked out well.

2 And I have run through some analysis work,
3 validation work, with actual flight test data. There's
4 another condition that we ordered up to do a final
5 validation and I haven't had time to go back and go
6 through that condition. But I'm satisfied, based on
7 the work that I've done, that the methodology is sound.

8 MR. SCHLEEDE: So there is flight test data
9 available for you to compare this analysis with to see
10 how close it matches?

11 THE WITNESS: Yes. We have a lot of flight
12 test data in our database. We don't have any
13 conditions similar to this, but conditions nonetheless
14 that would allow us to validate the method.

15 MR. SCHLEEDE: It may be evident from your
16 earlier testimony, but would any of this work have been
17 necessary if we had rudder position, aileron position
18 and lateral acceleration recorded on Flight 427?

19 THE WITNESS: I think that regardless of how
20 many parameters we'd have, we'd probably always go
21 through this analysis just to check the data for
22 validity. But of course, having those extra parameters

1 would eliminate a lot of questions.

2 MR. SCHLEEDE: Okay. And the last thing.
3 Did you do any similar analysis of the United 737
4 accident at Colorado Springs?

5 THE WITNESS: No. I was not involved in that
6 at all. This is my first investigation.

7 MR. SCHLEEDE: Are you aware of any similar
8 calculations and analysis that have been done on the
9 data from that accident, a kinematic type analysis?

10 THE WITNESS: I believe that all of the work
11 done on that, what little I know of it, was done
12 basically with just the simulator and trying to match
13 the data as the standard procedure has been in the
14 past.

15 I think this is the first time that I know of
16 that we've gone through this kind of exhaustive
17 kinematic analysis of the data.

18 MR. SCHLEEDE: So to your knowledge, there's
19 not been any comparison of the Colorado Springs data to
20 your analysis that you've described today?

21 THE WITNESS: That's right.

22 MR. SCHLEEDE: Thank you, sir.

1 CHAIRMAN HALL: Mr. Laynor?

2 MR. LAYNOR: No questions.

3 CHAIRMAN HALL: Well, let me first, Mr.
4 Dellicker, thank you for your explanation of a
5 kinematic study. I felt that was well done and very
6 helpful.

7 And again, let me comment on the work you
8 have accomplished in assisting -- and the time you
9 spent on this assisting the Performance Group in their
10 work. My only, -- I have no questions. My only
11 comment is that you certainly seem extremely able in
12 what you do and I only wish and I will hope that we
13 have more information and more parameters for you to be
14 able to work with.

15 In this accident we obviously don't. I
16 certainly hope that that's an area the Board is going
17 to promptly look at.

18 You're excused. Thank you very much.

19 THE WITNESS: Thank you.

20 (Witness excused.)

21 CHAIRMAN HALL: If we would please call Mr.
22 James Kerrigan. He is being recalled. I don't think

1 that's a negative connotation in this situation, Mr.
2 Kerrigan.

3 Mr. Kerrigan is being recalled to testify.
4 He has previously been sworn. He is, as you may
5 remember, a principal engineer in the Boeing 737
6 Aerodynamics, Stability and Control Group with Boeing
7 Company in Seattle, Washington.

8 (Witness testimony continues on the next
9 page. |

10

11

12

13

1 JAMES KERRIGAN, PRINCIPAL ENGINEER- 737 AERODYNAMICS,
2 STABILITY AND CONTROL, BOEING COMMERCIAL AIRPLANE
3 GROUP, SEATTLE, WASHINGTON
4

5 (Whereupon,

6 JAMES KERRIGAN,
7 was recalled as a witness on behalf of the NTSB, and,
8 having been previously duly sworn, continued his
9 examination and testimony as follows:)

10 CHAIRMAN HALL: Mr. Jacky, I believe the
11 witness is yours.

12 MR. JACKY: Welcome back, Mr. Kerrigan.

13 THE WITNESS: Thank you.

14 MR. JACKY: First of all, I was wondering
15 were you present for Mr. Dellicker's testimony?

16 THE WITNESS: Yes, I was.

17 MR. JACKY: Do you have any comments or
18 comparisons of the data that was involved in the
19 kinematic study versus the data that was extracted
20 using the backdrive of the simulation?

21 THE WITNESS: Yes. We have compared the two
22 methods. I've forgotten what the exhibit number is. I

1 believe that's Exhibit 13-N, page 1.

2 What this shows is a comparison of the side
3 slip angle that Mr. Dellicker determined from his
4 kinematic solution and the side slip angle that was
5 determined from the simulator exercise, and also the
6 equivalent wheel position and the equivalent rudder
7 position.

8 The top of the chart is the side slip angle.
9 And you can see, there is a bit of a difference between
10 the two. And also, if you look at -- I don't have a
11 plot of angle of attack, but angle of attack also
12 showed some difference between the simulator and the
13 kinematic solution.

14 As you can see, though, the basic dataset for
15 the two methods is quite comparable. The equivalent
16 wheel position mirrors one another very well during the
17 early portions of the upset. During the latter
18 portions where the side slips are deviated quite a bit,
19 there's a fair amount of difference.

20 Again, the equivalent rudder angle that's
21 shown, that also shows pretty fair agreement. The
22 kinematic, again, shows a little more rudder than does

1 the simulator, and that's consistent with the increase
2 in the higher side slip angle that's being shown in the
3 kinematic solution.

4 We're currently in the process -- I should
5 point out that these two exercises were done totally
6 independently in the beginning. It became a good way
7 to check both one against the other to make sure that
8 we were going to get a consistent answer. And up to
9 this point when this data was plotted, the two methods
10 basically have been independent.

11 What we're currently doing on the simulator
12 is introducing the side slip angle and the angle of
13 attack from Mr. Dellicker's kinematic solution. And we
14 can also on the simulator, with that new information,
15 force the simulator to come close to matching those
16 parameters.

17 We're in the early stages of that, but the
18 results to date look very favorable. And these two
19 solutions, I think, will close onto a common solution
20 in the end.

21 MR. JACKY: Thank you.

22 Now if I could refer your attention to

1 Exhibit 13-B, page 4, this is the list of the simulator
2 failures or malfunction scenarios attempted. And I
3 know that earlier this morning Mr. Berven and Mr.
4 Carriker spoke to the results of these tests. But I
5 wanted to ask you first of all, did you participate in
6 these scenarios?

7 THE WITNESS: Yes, to some extent. My group
8 was responsible for the simulation that was used in
9 this exercise. And, of course, the Performance Group
10 of which I was a part was also instrumental in setting
11 up these exercises.

12 I did not participate from inside the cab.
13 One of the other gentlemen in my group was in the
14 cockpit. However, I was present during those
15 discussions of the results.

16 MR. JACKY: And for reference sake, that is
17 the M-cab simulator?

18 THE WITNESS: Right. This was all conducted
19 in the M-cab simulation of the 737-300.

20 MR. JACKY: Okay. I believe earlier this
21 morning it's my understanding that Mr. Berven and Mr.
22 Carriker both estimated or thought that perhaps out of

1 all the simulators or the items looked here, the best
2 estimate or the best match of what early upset, as
3 indicated by the FDR trace, may have been Item 2(b) and
4 (c), basically the rudder hardover rate somewhere
5 between 2.5 degrees and 5 degrees per second.

6 Are you familiar enough with the data in
7 order to make some sort of characterization as to that
8 same characterization?

9 THE WITNESS: Well, I think in terms of the
10 yaw rates that were being set up by that kind of an
11 input from the rudder, along with the pilot's reaction
12 in terms of wheel, that that yaw rate was pretty
13 similar to what was seen in the flight data recorder
14 from USAir 427. However, the oscillatory beginning of
15 that flight data recorder I don't think was really
16 indicated by any of the tests that were done during
17 this simulator exercise.

18 MR. JACKY: So in other words, none of these
19 were able to match the FDR data exactly?

20 THE WITNESS: No. Nothing here was very
21 close to that initial roll back and forth. Generally,
22 I think when you put the rudder in at a constant rate,

1 what tends to happen is you get a fairly rapid change
2 in heading angle, but the roll oscillation generally
3 speaking isn't as pronounced.

4 MR. JACKY: Okay. Now if I can refer your
5 attention to Exhibit Number 10-B, which is Ancillary
6 Flight Data Recorder Study. What this study basically
7 is is a comparison of different plots or different FDR
8 data from USAir 427 as compared to other incidents and
9 accidents concerning 737 aircraft.

10 What I would like to do is go through each
11 one of these incidences and to look at a couple of the
12 data plots and to get your testimony or
13 characterization of are there any sort of similarities
14 or are the data not similar at all in these instances.

15 The first one that I would like to concern is
16 the United Airlines 585 accident which happened on
17 March 3rd of 1991. And there are several plots. I
18 believe nine different plots of data. And starting
19 with page number 13 of Exhibit 13-B -- or, I'm sorry --
20 10-B.

21 CHAIRMAN HALL: What page? 13?

22 MR. JACKY: I believe it's 13. The data may

1 also be in Exhibit 10-E -- 10-E, page 1.

2 CHAIRMAN HALL: It's page 13, Exhibit 10-B;
3 correct?

4 MR. JACKY: Yes. But what we've done is
5 taken the pertinent plots and placed them into Exhibit
6 10-E also.

7 CHAIRMAN HALL: Okay.

8 MR. JACKY: Okay. Have you or are you
9 familiar at all with the FDR data from this accident?

10 THE WITNESS: Yes. I worked on that accident
11 after it occurred.

12 MR. JACKY: Okay. And in the course of your
13 investigation of 585 and also with 427, have you had an
14 opportunity to compare the two sets of data?

15 THE WITNESS: Yes. We have looked at the two
16 accidents. And, of course, there are some similarities
17 in terms of what we saw occur on the airplane.

18 They did roll in different directions. The
19 585 airplane rolled to the right whereas this one
20 rolled left. And, of course, the 585 airplane was only
21 about 1,000 feet above the ground at the time of the
22 occurrence.

1 One of the things that is quite different
2 between the two airplane accidents is the weather. In
3 the case of USAir 427, the weather was quite calm prior
4 to the upset. In the case of UAL 585, the weather was
5 quite bad in the area. They spotted wakes or mountain
6 rotors, as they're called. Otherwise sometimes called
7 horizontal tornadoes that occur in that area, in the
8 area of the mountains. And the weather on that day was
9 basically referred to as a weather event, not uncommon
10 in that area.

11 As I recall, they figured they had probably
12 five days like that a year when the weather was
13 extremely violent.

14 We have -- well, we haven't found the
15 comparison plots yet, I guess.

16 (Pause.)

17 MR. JACKY: I guess we can work on without
18 it, but --

19 THE WITNESS: Okay.

20 MR. JACKY: Or unless -- well --

21 CHAIRMAN HALL: What's the difficulty? Can't
22 find the slide?

1 MR. JACKY: Yes.

2 CHAIRMAN HALL: Well, why don't we proceed
3 and somebody go over there and assist and proceed
4 ahead.

5 MR. JACKY: I apologize.

6 THE WITNESS: Yes. Some of the plots that
7 are shown in the exhibit for the case of UAL 585 were
8 not available on the flight data recorder, as Mr. Clark
9 pointed out in the last witness' testimony. The flight
10 data recorder on the UAL 585 was only referred to as a
11 six channel and that basically means from our
12 standpoint there are four channels of usable data.
13 They include the load factor, the heading, airspeed and
14 altitude. The other two channels are time and radio
15 transmissions, I believe.

16 The plots that are included in the exhibit
17 include roll angle, pitch angle, and also pitch and
18 roll rates, which were derived from an NTSB match of
19 that data. That's very -- I think to a large extent
20 speculation.

21 We also have done a similar match at Boeing
22 and come up with fairly different pitch and roll

1 angles. The one other problem that exists in that
2 dataset is that the directional gyro that's used to
3 determine the heading on that airplane is an old type
4 of gyro or an old type of system for determining
5 heading.

6 And once the pitch and roll departs
7 significantly from level flight, there can be some very
8 significant errors in that heading, so it becomes very
9 unuseful after say 50 degrees of bank and maybe 10
10 degrees of nose down pitch. The heading can have an
11 error of 20 degrees and it gets very much worse as you
12 go further in bank. So it's difficult to use that
13 throughout the maneuver.

14 As to whether there are similar causes to
15 that accident, we really don't know. And the match
16 that we put together which hits all the radar points
17 available during that maneuver and also puts the
18 airplane at the impact site, there was no rudder
19 involved in our match. The rudder was held within the
20 yaw damper's capability.

21 It becomes very difficult with only four
22 parameters to really accurately determine what happens

1 to that airplane. However, as I mentioned, the weather
2 that day was very bad, extreme, and with indications of
3 mountain rotors in that area. And the winds that we
4 calculated in our match of that data are very much
5 within the winds that were present on that day.

6 And Boeing believes that the weather in that
7 case was the probable cause. And I think that was part
8 of what was cited in the NTSB final report.

9 MR. JACKY: You mentioned that it was your
10 belief that the weather was very bad or very turbulent,
11 if I could add that word. In terms of the data, how
12 would that be or where would that be most exhibited?

13 THE WITNESS: Well, in terms of the data,
14 mainly load factor, the normal acceleration on the
15 airplane, I don't know if it really shows enough -- ah,
16 we have your chart.

17 If we go down to chart 18 in that set, it
18 shows the normal load factor and if you -- the upset on
19 that airplane, as you look at the time, the time there
20 is from USAir 427. But if you look at the time from
21 125 to 150, it shows some rather violent load factor
22 spikes. Not violent but very -- they are the same

1 order of magnitude in terms of up and down motion as
2 USAir had laid in the flight, and yet that was the
3 atmosphere that he was flying in.

4 The upset on Colorado Springs, I believe
5 didn't start until -- on this scale, maybe 150.

6 Let me look at roll rate. Yes. Somewhere
7 between 145 and 150 is where the actual upset to that
8 airplane occurred. So you can see prior to that
9 there's extreme load factor. It would have been a very
10 uncomfortable flight to have been riding on.

11 CHAIRMAN HALL: Now, Mr. Jacky, could we get
12 the page number on the record, please?

13 MR. JACKY: I believe there's a difference in
14 the plots. The one that Mr. Kerrigan is referring to
15 is I believe Exhibit 10-B, page number 18. However, it
16 appears as if the plot that's shown in Exhibit 10-E,
17 page 6 is -- the time has been skewed a little bit.

18 CHAIRMAN HALL: Well, let's get this
19 confusion resolved here and at this time take a break
20 for 10 minutes until a quarter 'til, and then let's
21 have it back in order.

22 (Whereupon, a recess was taken.)

1 CHAIRMAN HALL: The hearing will be back in
2 session. I'm told we're ready to proceed.

3 Is that correct, Mr. Jacky?

4 MR. JACKY: Yes.

5 CHAIRMAN HALL: Appreciate everyone's
6 patience. Please proceed.

7 MR. JACKY: My apologies.

8 Rather than attempt to go through all the
9 charts of all these instances, I would rather like to
10 ask you if you're familiar with the listings or with
11 the datasets of these incidents and accidents.

12 THE WITNESS: Yes.

13 CHAIRMAN HALL: One moment.

14 Again, I ask if you're going to have
15 conversations, please take them outside of the ballroom
16 so that those in here we can have the attention and
17 everyone will have the opportunity to listen.

18 Go ahead. I'm sorry.

19 THE WITNESS: Yes. We have looked at the
20 majority of them. There are a few that we have barely
21 touched upon, but the majority of incidents and
22 accidents we have examined at Boeing.

1 MR. JACKY: In the listing of these
2 accidents, as best you can recall, are you aware of any
3 similarities between the datasets off of these flight
4 data recorders and the data traces from USAir 427?

5 THE WITNESS: We've already talked about the
6 Colorado Springs accident. I think of all the other
7 accidents, the data that's listed there, none of them
8 are particularly similar to this accident in character.

9 The incidents that are there include it looks
10 like yaw damper type hardovers which are easily
11 controlled by the pilot and don't appear to have been
12 any hazard to the airplane in particular.

13 MR. JACKY: When you mentioned the yaw damper
14 incidents, to which of the datasets are you referring
15 to?

16 THE WITNESS: There's one that occurred at
17 San Pedro Sula in Honduras, a Continental airplane.
18 That one in particular was looked at pretty hard at
19 Boeing. We put together a simulation of it and the
20 initial event appears to have been a yaw damper
21 hardover which resulted in only a 9 degree bank angle,
22 which was quickly corrected by the pilot.

1 We don't understand everything about that
2 event. The yaw damper failure that caused that should
3 have disappeared. The rudder should have returned to
4 center and the rest of the flight should have been
5 normal.

6 Pilot reports indicate that he continued to
7 have to hold some wheel, and we don't necessarily
8 understand that. We have actually conducted one flight
9 test at Boeing to evaluate that circumstance. And
10 unfortunately, the configuration of the autopilot
11 wasn't quite the same, so we intend to conduct another
12 test shortly to look at this particular incident and
13 see if we can recreate what happened to this pilot.

14 We don't believe, however, that what happened
15 here would have any bearing on this USAir 427 accident.

16 MR. JACKY: Are you aware of any other
17 accidents or incident flight data recorder information
18 that might be comparable to USAir 427?

19 THE WITNESS: Well, in the list of items
20 you've given, there is a 737 -- I believe it was a 500
21 that got into a wake upset in Denver. And those places
22 basically show some similarities to what we see in the

1 USAir 427. Obviously it was not a loss of an aircraft
2 or even a serious upset in that case. The airspeed
3 trace shows to be very similar in terms of the airspeed
4 spike that occurs as he enters the wake and also
5 there's a load factor bump that's not dissimilar from
6 what we see in the USAir accident.

7 And when we -- we have not analyzed this one
8 at Boeing as yet. We do have the data available and
9 we'll be pursuing that in the near future. It does
10 show a fairly significant roll upset to about 20
11 degrees bank. And while that's not by any means a
12 safety of flight issue, at any time the airplane is
13 banked over and uncommanded and it rolls to any angle
14 it's an area that we're concerned about. We'd like to
15 understand what's happening.

16 In this case I think this wake may allow us
17 to run through like the kinematic solution and perhaps
18 we can determine if the wake that this guy ran into is
19 similar in magnitude to the wake of USAir 427.

20 So I think there may be some positive
21 information that will come out of that.

22 CHAIRMAN HALL: Could we get Mr. Laynor's

1 microphone on, please?

2 MR. LAYNOR: Just for the record, while you
3 don't have to refer to the charts in this exhibit in
4 detail, could you identify the flights and the pages,
5 perhaps, that the data you're discussing appear on?

6 I think the first one that you discussed was
7 Continental N17344 and perhaps you can identify the
8 last. That was the Honduras.

9 THE WITNESS: Yes. That was the Honduras.

10 MR. LAYNOR: And perhaps you can identify the
11 one that you're discussing when you're discussing the
12 wake encounter by the identification as it appears in
13 the exhibit.

14 MR. JACKY: If I can answer that, the wake
15 encounter that he's referring to is in Exhibit 10-B,
16 starting with page 22.

17 MR. LAYNOR: Thank you.

18 THE WITNESS: Okay. As I said, that is a
19 condition that we will be looking at at Boeing and
20 hopefully be able to get some wake information out of
21 it.

22 I think that that's something that we will be

1 doing at Boeing. The magnitude of the wake vortex can
2 very probably be determined from wake encounters that
3 occur in -- as long as they have sufficient parameters
4 on the flight data recorders and if the recorder is
5 pulled and sent to us within the 24-hour flight hours
6 after the occurrence, it's possible that we can get
7 some reasonable data out of that encounter.

8 Preferably, we need it from both the trailing
9 and generating aircraft, which is not always easy to
10 do.

11 We also, of course, require the weight and
12 speed and configuration of both the trailing and
13 generating airplanes. And success in actually deriving
14 some useful information from that is also going to
15 depend on the weather at the time. An incident like
16 Colorado Springs where it was a serious upset, the
17 weather is such that it's very difficult to deal with
18 the accident from a kinematic standpoint.

19 What we really need is light steady winds, no
20 gusts to speak of, in order to really fully realize
21 that data.

22 And one other thing in that regard. We have

1 considered, and I think continue to consider actually
2 going out and flying a 737 behind a 727. We would hope
3 that that would be a Performance Group or NTSB-NASA-FAA
4 and industry representative study that we could conduct
5 and perhaps gain some useful information.

6 Unfortunately, Boeing doesn't, believe it or
7 not, doesn't own any airplanes, 727's or 737's, so
8 we're going to have to borrow or lease an airplane from
9 an operator or, in the case of the -- the FM, I
10 believe, has a '27, so we'll be hopefully working that.

11 MR. JACKY: Thank you.

12 Earlier this morning, Mr. Berven and Mr.
13 Carriker gave some testimony regarding yaw damper
14 effects and pilots' actions. And there have been some
15 other testimony to that. Are you aware or would you
16 expect to see any sort of yaw damper activity in a wake
17 vortex encounter, especially if we saw some sort of
18 heading change or yawing moment?

19 THE WITNESS: Well, in any wake encounter
20 what we expect is the bank angle is going to wobble a
21 little bit and there may or may not be infringement of
22 the wake on the vertical tail of the airplane.

1 In either event, there's going to be some
2 changes in heading, some heading rate that will be set
3 up. And the yaw damper reacts to heading rate. That's
4 what makes it work.

5 So you would expect that the yaw damper would
6 be active. How much of a control input it would make
7 is going to depend on how violent the rate, the yaw
8 rate is on the airplane.

9 Generally, I wouldn't expect that it would be
10 going to its full authority but it's possible in an
11 extreme wake that it might.

12 MR. JACKY: Thank you. Now I'd like to refer
13 you to Exhibit 10-D, please, if I may, and specifically
14 page 3. And we asked Mr. Dellicker this question and I
15 would like to ask you the same question, if it's
16 available.

17 What parameters that are shown in these two
18 lists would be helpful to you in terms of your
19 investigation? Most specifically, during the
20 backdrive.

21 THE WITNESS: Well, as Mr. Dellicker said, we
22 certainly could have benefitted in this investigation

1 with any of the control inputs that would have been
2 available and lateral acceleration. Our preferences as
3 an engineer would be to get as many parameters as we
4 possibly can, of course.

5 We certainly would like to have both the
6 control input in the cockpit and the resulting control
7 surface movement, such as column and elevator, wheel
8 and aileron and spoilers, rudder peddles and rudder
9 position. It also, of course, would be very useful to
10 have the forces involved; rudder peddle, column forces,
11 wheel forces.

12 Lateral acceleration, obviously, would add a
13 lot of information to our -- as far as lateral
14 directional upsets would be concerned.

15 MR. JACKY: What would be or is there a
16 benefit in having both a commanded position and the
17 actual aircraft position? For example, say control
18 wheel and aileron position.

19 THE WITNESS: Well, in case of the aileron,
20 the lateral control system, there's obviously a lot of
21 different components to that. If one of them fails or
22 isn't working for some reason, the wheel won't tell you

1 that if that's the only parameter you've got.

2 On the other hand, if you have all the
3 control surfaces, you may be able to get by without
4 wheel. We don't know of any failure that would cause
5 the aileron and the wheel to not be in perfect
6 agreement.

7 In the case of the rudders, however, you have
8 rudder peddle and you have rudder position. The yaw
9 damper is in series in this airplane. The peddles
10 don't move and the yaw damper puts an input into the
11 rudder. So unless you have both of those parameters,
12 you really can't be sure what the yaw damper is doing.

13 So in that case, we would very much like to
14 have both.

15 MR. JACKY: Thank you.

16 Are you generally familiar with the Boeing
17 727 rudder system?

18 THE WITNESS: Yes. I've worked on the 727
19 for quite a number of years as a lead engineer in
20 Stability and Control, so I'm familiar with that
21 airplane.

22 MR. JACKY: Can you briefly describe the

1 general differences between the 737 and 727 rudder
2 package?

3 THE WITNESS: Well, in general terms, the 727
4 has a split rudder, an upper and a lower rudder. The
5 PCU that drives the two I think you need to talk to
6 some of the systems people about, but my understanding
7 is it's not a dual valve servo. It's a single valve
8 servo on both the upper and lower rudder.

9 The hydraulic pressure to the rudder on the
10 727 is much lower than on the 737. The upper rudder
11 has an 800 psi maximum all the time. The lower rudder
12 is 2450 psi on the lower rudder for flaps down
13 operation. And when the flaps are put up, the pressure
14 is reduced to 800 psi.

15 The other similarities, I guess, are it's a
16 cable driven system, very similar. From the cockpit on
17 back to the tail it's quite similar.

18 MR. JACKY: What would happen to the airplane
19 if a 727 rudder PCU moved hardover?

20 THE WITNESS: Well, from a systems
21 standpoint, again, you need to talk to the systems
22 people. I believe that if one PCU was driven hardover,

1 the other one would still be available to counter that
2 input. However, even if both rudders went hardover on
3 that airplane or driven to the blowdown limit, because
4 of the reduced pressure available to the rudder, the
5 amount of lateral control to control it is quite small.
6 It takes about 25 degrees of wheel to keep the wings
7 level with a rudder hardover in that airplane. And
8 that's about 15 percent of the available lateral
9 control.

10 MR. JACKY: Have you personally been involved
11 in the investigation of any upset occurrences in other
12 Boeing aircraft?

13 THE WITNESS: Yes, I have been involved in
14 quite a number of accident investigations. As I
15 mentioned yesterday, including the 727 TWA event, I've
16 been involved in a number of windshear accidents that
17 have occurred on the 727 and some -- and also at least
18 one 707 accident that I can recall

19 (Pause.)

20 MR. JACKY: I have no further questions.

21 CHAIRMAN HALL: Any questions from the
22 parties?

1 Yes, Captain, with the Airline Pilot's
2 Association.

3 CAPTAIN LeGROW: Thank you, Mr Chairman.

4 Good afternoon, Mr. Kerrigan. Just a couple
5 of quick questions.

6 First of all, you testified earlier that in
7 the USAir 427 accident the airplane rolled and upset to
8 the left. You also stated that the Colorado Springs
9 United Airlines 585 airplane rolled and upset to the
10 right. Is that correct?

11 THE WITNESS: Correct.

12 CAPTAIN LeGROW: Is it not true that both
13 USAir 427 and United Airlines 585 both rolled and upset
14 in the direction in which they were turning at the
15 time?

16 THE WITNESS: Let me -- if I could check the
17 record. I don't remember off hand. I believe the --
18 yes. I believe that's right. That's correct. It was
19 a 20 degree bank.

20 CAPTAIN LeGROW: Thank you.

21 Also, you stated earlier that the Colorado
22 Springs 585 United accident, the Safety Board believed

1 that the accident was weather related. Is that
2 correct?

3 THE WITNESS: They had I believe cited that
4 as a possible cause.

5 CAPTAIN LeGROW: To my knowledge, and maybe I
6 missed it, but did the Safety Board find a probable
7 cause for United 585?

8 THE WITNESS: I don't know that they found --
9 they positively identified a probable cause. I said a
10 possible cause, which is a bit different in their
11 terminology.

12 CAPTAIN LeGROW: Okay. Thank you. I have no
13 further questions.

14 CHAIRMAN HALL: Other questions from the
15 parties?

16 Boeing.

17 MR. MCGREW: Yes, Mr. Kerrigan. Two
18 questions.

19 Would you comment, please, on the sample rate
20 and your views of what data recorder sample rates might
21 be doing to our analysis?

22 THE WITNESS: Okay. Yes. As Mr. Dellicker

1 mentioned, the sample rates, particularly for the kind
2 of analysis that he is conducting for the kinematics,
3 is quite important and an increased sample rate would
4 benefit that kind of an analysis very much.

5 From a simulator standpoint, there's also
6 benefit. It would be extremely beneficial, I would
7 think, to have things such as heading at much more than
8 a one sample per second rate.

9 MR. MCGREW: Thank you very much.

10 CHAIRMAN HALL: Any other questions?

11 Mr. Marx?

12 MR. HAUETER: Excuse me, Mr. Chairman.

13 There's a question in the back.

14 CHAIRMAN HALL: Okay. Yes.

15 Mr. Wurzel? Wurzel. I'm sorry. Yes. With
16 the International Association of Machinists. Please --

17 MR. WURZEL: One question, Mr. Kerrigan. A
18 few questions here.

19 To your knowledge, is it not true that UAL
20 Flight 585 had reported uncommanded rudder movements
21 during previous flights?

22 THE WITNESS: My understanding is that there

1 had been some pilot complaints about that airplane and
2 that some steps had been taken to try to correct that
3 in the rudder -- the yaw damper control system.

4 MR. WURZEL: And also, the weather in
5 Colorado Springs, I believe you stated, was kind of
6 questionable that day, but the weather report shows it
7 was VFR with 32-35 miles an hour gusts. Lighter
8 aircraft than the one that had crashed had landed
9 before that.

10 Do you know anything about that?

11 THE WITNESS: That's very possible. The
12 onset of what was called the mountain rotor is
13 something that's very localized. The size of a
14 mountain rotor can vary anywhere from probably airplane
15 size, 100-200-300 feet across, to up to perhaps a
16 couple of thousand feet across. And airplanes could be
17 landing safely if they didn't encounter such a -- the
18 rotor, and still have an airplane that gets into the
19 core of the rotor and has control difficulties.

20 MR. WURZEL: In that area, do you know of any
21 other aircraft that had ever encountered any of those
22 large type rotors?

1 THE WITNESS: I don't know that there had
2 been any specifically in Colorado Springs. People that
3 fly in that area, as I understand it, frequently do
4 encounter mountain rotors, generally on that side of
5 the Rocky Mountains there's, I believe, encounters.

6 I can't specify one for you right now but
7 there have been other encounters.

8 MR. WURZEL: That concludes my questions.
9 Thank you.

10 CHAIRMAN HALL: Thank you.

11 Mr. Marx, you have no questions?

12 Mr. Clark?

13 Mr. Schleede?

14 Mr. Laynor?

15 The Chairman's only question, I believe we're
16 going to have some individuals from Boeing that are
17 going to be testifying much later in regard to the
18 reporting system -- no, no. On incidents that occur in
19 regard to the stability and control of the Boeing 737.

20 Is that information routinely provided to
21 you, sir, and what is your role in that, as things are
22 reported, that may occur with the number of planes that

1 are out there operating?

2 THE WITNESS: Well, that's one of the primary
3 jobs of my group. We deal with customer inquiries of
4 all kinds. If an event like that is reported by an
5 airline, it comes in through Boeing Customer Service or
6 Flight Operations and somebody along the line makes a
7 judgment as to whether we need to be involved.

8 We don't automatically see every telex that
9 comes in. Of course, there's several thousand of those
10 I believe a day. It's a large number that arrives,
11 most of which don't involve stability and control.

12 But if it does involve the stability and
13 control of the airplane, it should be passed on to us
14 and I'm sure the majority of them are.

15 CHAIRMAN HALL: And just one more
16 observation. On the flight data recorder where you
17 mentioned a number of things you would like to have, I
18 assume that the state of technology is that those
19 things are presently available if an airplane is
20 properly equipped with a flight data recorder and the
21 electrical ability to get that data off?

22 THE WITNESS: Well, certainly the new

1 airplanes that are being produced have all of that
2 data, or most of it, recorded already, and it is
3 available. On the older aircraft it becomes a concern
4 because some of the parameters that we would like to
5 have that I would like to have recorded are not
6 necessarily readily available. So it isn't clearcut
7 that all aircraft out there, large jet transports, have
8 it readily available, the information we'd like.

9 And some of the parameters that I would like
10 to see, such as pilot forces, I don't know any of the
11 aircraft currently being produced include
12 instrumentation currently that has that has that
13 information available. I think the technology to add
14 that to the airplanes is probably there if we're
15 willing to pay the cost.

16 CHAIRMAN HALL: Okay. Well, Mr. Kerrigan, we
17 appreciate your appearing once and appearing twice. I
18 don't know whether we'll have you back for a third
19 time, but at this point you're excused.

20 THE WITNESS: Okay.

21 CHAIRMAN HALL: Thank you.

22 (Witness excused.)

1 CHAIRMAN HALL: The next witness is Mr.
2 Bernus Turner. He also is with the Boeing Commercial
3 Airplane Group out of Seattle, Washington. He is the
4 Boeing 737 Flight Controls Engineer.

5 (Witness testimony continues on the next
6 page.)

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17

1 BERNUS TURNER, B-737 FLIGHT CONTROLS ENGINEER, BOEING
2 COMMERCIAL AIRPLANE GROUP, SEATTLE, WASHINGTON

3

4 (Whereupon,

5

BERNUS TURNER,

6

was called as a witness by and on behalf of the NTSB,

7

and, after having been duly sworn, was examined and

8

testified on his oath as follows:)

9

MR. SCHLEEDE: Mr. Turner, please give us
10 your full name and business address for the record.

11

THE WITNESS: Full name is Bernus Gene
12 Turner. Address is Box 3707, Seattle, Washington
13 98124, I believe it is.

14

MR. SCHLEEDE: And you work for Boeing?

15

THE WITNESS: I do work for Boeing. Have
16 almost for 34 years.

17

MR. SCHLEEDE: In what position?

18

THE WITNESS: I'm currently the technical
19 manager of mechanical systems for the new generation of
20 737.

21

MR. SCHLEEDE: Give us a brief description of
22 your background and experience that qualifies you for

1 your current position.

2 THE WITNESS: In 1961 I graduated from the
3 University of California, mechanical engineering. Came
4 to work directly for Boeing on the 727 project. Went
5 over to the 737 project as a lead engineer in 1964 or
6 '65. Left there in '69. Worked on a variety of other
7 Boeing airplanes.

8 In 1986 I had been made a part of management
9 and I came back into the 737-757 project at that time
10 as a hydraulic supervisor. Stayed in Sustaining.
11 Moved up to unit chief in that same project and a year
12 and a half ago went to the new generation 737 project.

13 MR. SCHLEEDE: Thank you. Mr. Phillips will
14 proceed.

15 MR. PHILLIPS: Good afternoon, Mr. Turner.

16 In your experience, your 34 years with
17 Boeing, you've been involved with flight control
18 systems and hydraulic systems design for the extent of
19 your career. And I also note that you hold some
20 patents. Do any of those patents apply to any of the
21 flight control systems on the aircraft that we're
22 looking at today?

1 THE WITNESS: No. I think I have six active
2 patents. None of them happen to be on this particular
3 airplane, though.

4 MR. PHILLIPS: All right. And over the years
5 of your design experience, how long of that has been --
6 have you been involved with the 737 program in general?

7 THE WITNESS: First assigned to the 737. I
8 was the second hydraulics engineer assigned to the
9 program in 1964-65, something like that. Left it in
10 '69 as the lead engineer for flight controls working
11 power control packages. And like I said before, I came
12 back to the program in 1986 as a manager and have been
13 associated with the 737 in one capacity or another ever
14 since.

15 MR. PHILLIPS: In the course of your duties
16 at Boeing, have you been involved in any of the
17 accident investigations involving 737 aircraft?

18 THE WITNESS: Yes. I was active in the
19 Colorado Springs 585 at the time. This particular
20 program or accident I've not been directly associated
21 with it. Some time ago, I was asked to come in and
22 take a look at what the systems folks were doing,

1 offering expertise, any background, any experience,
2 anything I might be able to add to the program.

3 MR. PHILLIPS: With Mr. Chairman's
4 indulgence, we've made several attempts today and in
5 the last couple of days to talk about the flight
6 control systems. Pilots have describe it and Stability
7 and Control people have described it. And what we'd
8 like to do is ask a systems person to take a stab at
9 explaining some of the functions of flight control
10 systems.

11 Mr. Turner is prepared to go through the
12 systems with the general description and we'll stop and
13 get more specific in the areas we're interested in. So
14 if you could start us off, I think we're referring to
15 Exhibit 9-S this time.

16 CHAIRMAN HALL: Are we going to show a number
17 of slides again as we go?

18 MR. PHILLIPS: Yes.

19 CHAIRMAN HALL: Well, let's see if we can't
20 do something about the lights so everybody can see.

21 Thank you, sir.

22 MR. PHILLIPS: What I'd like to start with is

1 just a general description of all the flight control
2 systems and as we get into the systems, a little more
3 specific about the rudder control system.

4 THE WITNESS: The airplane is very
5 conventionally laid out. Ailerons and spoilers on the
6 wings which we've seen in this chart before. That's
7 used for lateral control. The pitch control is
8 basically an elevator, a pair of elevators on each side
9 of the airplane with a movable stabilizer for trim.

10 A single rudder for directional control which
11 incorporates both the main rudder throw and the yaw
12 damper control.

13 CHAIRMAN HALL: Pitch is up and down?

14 THE WITNESS: Pitch is up and down. Yaw is
15 sideways. Lateral is roll.

16 Fundamentally, if we look at the next chart
17 what one can see there is the airplane is basically a
18 hydraulically fully powered control airplane with a
19 manual backup. What that really says, that we have
20 primary flight controls on two hydraulic systems. If
21 the two hydraulic systems are inoperative, there's the
22 cable system. That is, the airplane can in fact drive

1 the surfaces directly through pilot effort.

2 If you'll look at the elevators, there's a
3 set of control columns, one for each pilot, in the
4 front of the airplane. Two sets of cables go back to
5 the tail of the airplane. The cables run pretty much
6 right underneath the floor and the floor beams.

7 In the tail of the airplane we have two
8 single system hydraulic packages bused together on a
9 single bus torque tube. The output of those two
10 packages go through a set of push rods out and drive
11 the elevators.

12 It isn't clear to se here but the input
13 cranks that are connected to the cables, motion comes
14 in and that commands the package to go up or down. If
15 the package is inoperative because of no hydraulic
16 system pressure, then there's some manual stops about
17 two degrees, 2-1/2 degrees -- something like that --
18 backlash, and that link would bottom out. That enables
19 the pilot to drive the surface directly through pilot
20 effort.

21 Needless to say, the forces to operate the
22 surfaces directly without any pilot boost are somewhat

1 higher, considerably higher than the power to just move
2 the controls directly.

3 The next chart is the stabilizer control
4 system, the other half of the pitch control system, and
5 there's a jack screw at the tail of the airplane that
6 pivots the whole stabilizer. That's an electric system
7 where there is trim switches on the control columns,
8 and through the trim switches you have an electrical
9 signal that goes back to this jack screw driven by an
10 electric motor, and that can position the stabilizer
11 directly to the pilot's trim commands.

12 We have a cable system and a crank, so to
13 speak, in the front of the cockpit, a stabilizer trim
14 wheel. And by turning those trim wheels you can
15 manually position the stabilizer as a backup.

16 So between the elevators and the stabilizers
17 you manage the pitch control of the aircraft.

18 The lateral system gets to be a little more
19 complex. As Mr. Rusko described earlier, you start
20 with the two control columns, the wheels, and a set of
21 cables that drive down into the wheel well. Signals
22 off of these cables go down and drive the main power

1 control packages. They happen to be identical packages
2 to the elevator, single system driving on a single bus
3 torque tube.

4 The signals go into the packages. The
5 packages respond in the appropriate direction, drive
6 the cable system that actually drive the aileron. The
7 other set of cables go over to a spoiler system and
8 through the spoiler mixer box, they drive spoilers to
9 augment the ailerons.

10 There is an override protection device. If
11 for some reason or another the ailerons become jams,
12 one can, through the co-pilot's wheel, rotate, go
13 through and override mechanism on the bottom of the co-
14 pilot's column there and drive the spoilers
15 directly. So there's jam protection in there.

16 The rudder peddle is the one system that does
17 not have a manual backup. Here we have a third
18 hydraulic system and another hydraulic power control
19 package.

20 At the front of the airplane is two sets of
21 rudder peddles. This particular chart shows one.
22 There's a set for each pilot and co-pilot.

1 The rudder peddles themselves drive a linkage
2 train; goes back and drives quadrants. The quadrants
3 are bused together from right-hand to left-hand side of
4 the aircraft. They run a single cable system. The
5 single cable system goes back to the tail of the
6 airplane with a field and centering unit.

7 And let's see. Probably in the next chart
8 there's a little bigger scale on the field and
9 centering. There's a field and centering unit there in
10 the tail of the airplane, and what that really is is
11 it's a cam and spring. And when the pilot moves the
12 rudder peddles he actually moves that cam and spring
13 and that gives him an artificial feel he's pushing
14 against something.

15 And so when you push on them, you can -- you
16 know, just by -- I think its about a 12 pound, 12-15
17 pound brake up to about 150 pounds, you get tactile
18 feedback off of your field system. And then that same
19 control quadrant is attached to a torque tube. The
20 torque tube transmits signals to the main rudder power
21 control package as well as simultaneously transmitting
22 signals to the standby actuator.

1 So fundamentally, you mash on the rudder
2 peddle. That moves the cables. The cables move the
3 field and centering unit; moves the linkage train that
4 tells the main power control package where to go and it
5 positions that way.

6 In the event that the main rudder power
7 control package, which is a dual hydraulic system, dual
8 load path unit, is operative, two hydraulic system
9 fails, then the third hydraulic system is actuated and
10 that power is slowed to the standby actuator, which is
11 the single system, single load path system.

12 So fundamentally, most of the time when you
13 use standby package is if you happen to be on a manual
14 reversion, then you have the rudder to augment your
15 elevator and lateral manual system.

16 The next chart gives somebody an idea of the
17 complexity in the dual load path dual system hydraulic
18 power control package. Rather than try to get into the
19 details of how this thing works, I think it would
20 suffice to say that through an input linkage you get a
21 signal that comes in through an interior set of
22 linkages and drives the main control valve, which

1 happens to be a dual concentric tandem device. It's a
2 valve within a valve and there's two hydraulic systems,
3 so it's a tandem valve.

4 We'll get into -- I think Paul Cline has got
5 some videos later on that may help explain how this
6 complicated linkage works.

7 Incorporated in there is a yaw damper
8 actuator. That's a piston that's driven by what we
9 call a transfer valve. The transfer valve takes
10 electrical signals, converts them to hydraulic signals,
11 goes down and moves this yaw damper piston. The yaw
12 damper piston moves. It drive the linkage train and
13 via the feedback linkage, the rudder moves in direct
14 proportion and only as far as this yaw damper piston
15 can move.

16 So if it doesn't move, the rudder doesn't
17 move. If it moves the equivalent of three degrees,
18 which is on this airplane, that's how far the rudder
19 can move.

20 Incorporated in the power control package, as
21 well as the main power piston, is a series of bypass
22 valves. And incorporated in this bypass valve is an

1 orifice. And the function of that orifice is to bypass
2 fluid from one side of the piston to the other.

3 We found when we fired up our flight control
4 tests quite some number of years ago, the system was
5 unstable and had a limit cycle. It would sit there and
6 shake back and forth, and so we had some changing of
7 gains within the servo system to do. And one of the
8 things we did to add stability to the system was put
9 this bypass orifice in there.

10 And so any time you have a small command to
11 the package, the first thing that happens, fluid flows
12 through the orifice and then as you put large commands,
13 you swamp out the orifice and the rudder package
14 actually moves.

15 Also incorporated in there is a couple of
16 filters -- and we'll probably talk about filtration a
17 little later -- to filter any incoming fluid that comes
18 into the package. There's also an interconnect check
19 valve and that interconnect check valve keeps fluid
20 from ever flowing backwards through the package. And
21 we'll probably talk about that a little bit more.

22 Why don't we skip on to chart Number 9.

1 Greg, I'm just following the outline here, so
2 just jump in if you need to.

3 MR. PHILLIPS: That's fine. We'll back right
4 back up where we need to ask some questions.

5 THE WITNESS: Okay. Page number 9 is the
6 standby hydraulic power control package and it has a
7 double bypass, if you want to call it that. The main
8 control valve has a dead band in it, so that any time
9 the command signals is within one degree of the
10 position of where the rudder actually is, the valve
11 just has a bypass that bypasses both sides of the
12 piston to each other.

13 It also has a bypass valve in it that's
14 pressure operated. And what that double bypass is for
15 is the airplane is certified to be good for any single
16 failure and so since we have two bypasses here, this
17 prevents having a hydraulic lock so that the main power
18 control package would be forced to not move if this
19 thing malfunctioned. And so we have bypassed the main
20 control valve and then a bypass valve. So we always
21 have freedom of motion for the main rudder power
22 control package.

1 So this thing is really just a manual
2 control. It happens to be what we call a moving body
3 package. The body itself is mounted to the rudder and
4 when you put an input in from the pilot's rudder
5 peddle, the input crank moves, and then the body moves
6 to reestablish the non-relationship of the crank to the
7 body, and that gives you what we call an integral
8 feedback and positions the rudder directly proportional
9 to what's commanded by the pilot.

10 Now, I indicated that this was a single load
11 path versus a dual load path to the main package. And
12 we have to be good for any single failure. What that
13 says -- next chart, please. What that says is that if
14 that control linkage fails to move, if there's a
15 binding, if a bearing is bound up, if the main servo
16 valve has got a chip in it, no matter what someone may
17 be able to postulate, if that crank can't move the
18 airplane still has to perform satisfactorily.

19 Very early on we put a shear-out in. That
20 circled area there is where we had a shear out, and the
21 idea was that if you did in fact have a valve jam and
22 stopped this thing from moving, if you pushed on the

1 rudder peddle you could cut the shear-out off and
2 regain control of the main rudder power control
3 package.

4 What we found when we started testing this
5 device in the iron bird in probably 1967 or '68,
6 somewhere thereabouts, is that part labeled torque tube
7 is in reality a spring. It has enough spring rate to
8 it that when you fix the input rod on the standby
9 package, when the rudder commands came in from the
10 cable system at the bottom of that torque tube, the
11 torque tube would wind up or twist and give you direct
12 connection to the main rudder control package.

13 And it turns out that there was enough twist
14 in that torque tube that you just moved the rudder with
15 respect to normal commands, even though there was a jam
16 in the input rod of the standby package. And the thing
17 would drive to the limit of stop and we couldn't
18 actually cut the shear out, so the shear-out was taken
19 out.

20 So, the shear-out was taken out. I think we
21 only had 20 some airplanes that way and probably all of
22 them have been retrofitted.

1 So what we have there is a built in
2 compliance, the springiness in that tube. All you'd
3 have to do is put your feet on the rudder peddles
4 and/or the feet on the centering unit to provide enough
5 force to wind up that torque tube and position the
6 rudder in whatever position one would want to put it.

7 MR. PHILLIPS: I believe we were referring to
8 -- you were describing page 10, which we evidently
9 don't have a viewfoil for. Have you got that?

10 THE WITNESS: Okay.

11 MR. PHILLIPS: I think we were discussing 10
12 with the shear-out mechanism.

13 THE WITNESS: Right. It looks very similar
14 to your other one. It just has the location of the
15 shear-out that was in there originally.

16 MR. PHILLIPS: Are there any novel or unusual
17 features in the design of the 737 directional control
18 system?

19 THE WITNESS: In think you're probably
20 referring to the dual concentric servo valve, which has
21 gotten a lot of discussion.

22 A little bit of history. During the design

1 of the 727 we were looking at various methodologies to
2 take care of a phenomenon known as valve jam. If you
3 drop a chip or some such device, a large particle
4 contaminant into a servo valve and the valve fails to
5 respond, then that particular servo package would in
6 fact start to continue to go in the direction it was
7 commanded to go without feedback shutting the valve
8 off.

9 There's a lot of ways to take care of that
10 situation and different manufacturers, different people
11 have come up with different ideas. They tend to run in
12 valve jam detectors, mechanical and electrical, and
13 then detect a valve jam. And then usually electrically
14 turn off a valve that depressurizes the hydraulic
15 system and stop the runaway.

16 Well, this kind of a device, which is pretty
17 commonly used, requires some time to detect the valve
18 jam, then turn off the system, then bleed it down. And
19 so there's a dynamic situation where if you have a
20 valve jam you get some kind of overshoot or you can get
21 the system turned off.

22 The fellows that worked on the 727 in this

1 particular device -- I was not one of them right at the
2 start of it -- came up with a valve within a valve and
3 the objective of this valve was that it would -- if you
4 had a jam of the primary to the secondary because of a
5 chip, then the secondary would move and you would
6 actually dump both sides of the piston to return
7 pressure, which would depressurize the package
8 automatically with no time lag, no sensing, no
9 electronics, no maintenance, the things that go wrong
10 with electrical systems.

11 So, this device was intended to reduce the
12 pressure ideally so you could manufacture everything
13 exactly down to zero residual pressure across the
14 piston head. Of course, you can't do everything
15 perfect, so it's set up to reduce the pressure
16 somewhat. And the amount that it has to come down is a
17 function of where you happen to be using this thing;
18 the rudder, elevator, wherever.

19 Well, we put that on the 727 and it turns out
20 the guys that did the design got real clever. They
21 found that if the valve -- they could set up the pieces
22 so that if the valve jammed in any position except its

1 extreme travel, then you could retain some control over
2 the package.

3 If it jammed at neutral, for instance, then
4 the secondary would give you full hinge moment at 50
5 percent rate. If it jammed at full stroke of the
6 primary or secondary, then you ideally got zero hinge
7 moment at zero rate. And if it jammed anywhere in
8 between, then you got some benefit.

9 So what turned out being an automatic
10 depressurization device also provides some amount of
11 control, depending on where the jam occurs.

12 Working on a 737, since this device was
13 available, people recognized that if they put this in
14 the rudder of the 737, that if a valve jam occurred,
15 which historically, that happens on a package about
16 once every 10 million flight hours, then this thing
17 would reduce the amount of residual rudder that would
18 be there after a single valve jam or provide control,
19 depending on where the jam was.

20 And if you could reduce the amount of hinge
21 moment after a valve jam, then you increased your
22 amount of aileron residual that you had over rudders.

1 I heard a couple of times where you trade off rudder
2 versus aileron.

3 MR. PHILLIPS: At least two Boeing airplanes
4 that I'm aware of, the 727 which we discussed earlier
5 and the 747, have two rudder panels and independent
6 actuation packages. Can you discuss a little bit the
7 reasoning that Boeing had at the time for going to a
8 single package, dual concentric controlled system?

9 THE WITNESS: The preliminary design fellows,
10 when the airplane came out of PD, it had a single
11 rudder. I'm not exactly sure what it was. I suspicion
12 that it had to do with -- on this particular airplane,
13 configuration. It was probably lighter than a dual
14 rudder. That would be my guess.

15 Every airplane is different. The weight
16 tradeoffs are different for every airplane. And I know
17 that's a tradeoff that caused us to put a single slab
18 rudder on 757.

19 MR. PHILLIPS: And the 777, the triple 7, has
20 a single panel rudder?

21 THE WITNESS: Let's see. That's the one
22 commercial airplane I haven't worked on. Yes. I

1 believe it is.

2 MR. PHILLIPS: I don't know if you discussed
3 the rudder trim system. Could you briefly describe how
4 that operates?

5 THE WITNESS: Yes. I guess I skipped that.

6 If we go back to page 6, I believe, would
7 show it. On page 6 I commented that there was a field
8 and centering unit that -- when that's driven out of
9 its centered position, you get a rudder position
10 through the input linkage there.

11 What we do is to have an electric drive motor
12 and a little jack screw, and we actually rotate that
13 field and centering unit with a command of the switch
14 in the cockpit. So, by rotating a rudder switch on the
15 aisle stand, the little jack screw through an electric
16 signal, will rotate the field and centering unit. And
17 what that does it backdrives the cable system
18 positions, the rudder peddles offset to the potion
19 that's commanded, and moves the rudder over to offset
20 that's driven in by the trim system.

21 So we can trim up to about -- I think it's 14
22 or 15 degrees of rudder. And when you do that, the

1 rudder peddles are about 50 percent offset away from
2 their neutral position. The rudder peddles themselves
3 are tied directly through the control linkages to the
4 rudder itself through the main power control package.

5 It does have those manifold stops that I
6 indicated that the elevator package has, and that means
7 that the rudder position to the rudder peddle can only
8 be different by the amount of that small backlash
9 that's in the manifold stops. So the rudder peddles
10 will always follow physically the rudder, regardless of
11 what happens on the ground, the wind blows it, you name
12 it.

13 MR. PHILLIPS: I guess that brings us to the
14 yaw damper. That's the one time the rudder peddles
15 don't follow the rudder position.

16 THE WITNESS: That's correct.

17 Inside the package, as we commented, we have
18 a separate set of summing levers is what we call them.
19 And for that very, very limited stroke the -- let's put
20 it this way.

21 Within the 6 degrees that's in the valve -- I
22 think it's around 6 degrees. It's in the valve

1 backlash. The yaw damper can move the rudder peddles
2 three degrees, or move the linkages three degrees
3 without it getting back to the rudder peddles. And so
4 we have what we call a series input system where the
5 actual rudder position is a function of rudder peddle
6 plus the year damper.

7 And so as long as we stay within the valve
8 stop -- and the yaw damper certainly does -- then the
9 yaw damper can put a 3 degree input in. The feedback
10 linkage comes back and that doesn't feed back to the
11 rotor peddles. That's correct.

12 MR. PHILLIPS: What limits the yaw damper
13 input to 3 degrees?

14 THE WITNESS: It's the length of the piston
15 and the mechanical stops that it drives up. Again, the
16 piston is only so long and it can move about three-
17 tenths of an inch. That's the -- that it's in. It's
18 in cab, so it can only go two-tenths of an inch or
19 whatever the exact number is.

20 MR. PHILLIPS: Could you take us back up to
21 the front of the airplane with the coupler and bring us
22 through a description of the yaw input command from the

1 coupler back into the yaw damper and what the resulting
2 motion of the rudder would be?

3 THE WITNESS: Are you asking me is there an
4 indicator in the cockpit?

5 MR. PHILLIPS: That would be part of the
6 system. I'd like to -- I'd like to start with the
7 beginning of the sensing of a yaw input requirement and
8 then resolve that into the rudder movement.

9 THE WITNESS: Fundamentally, when the
10 airplane yaws or swings sideways, we have devices
11 called rate gyro, and it's a gyroscope. And as the
12 airplane rises, the gyroscope creates an electrical
13 signal in proportion to how fast the airplane changes
14 direction.

15 That electrical signal is processed through a
16 yaw damper coupler, a magic black box that I can't add
17 too much to. And the computed signal goes back to
18 the rudder package. That commands the transfer valve.
19 The transfer valve puts fluid to this little yaw damper
20 cylinder or yaw damper piston, moves the piston, and
21 then that opens the valve.

22 The rudder itself moves. The feedback

1 linkage comes back and shuts the valve off, and then
2 that's it in a nutshell, I guess, unless you try to get
3 me to explain the black box.

4 MR. PHILLIPS: I believe we'll pass on that.

5 And there is an indication in the cockpit of
6 the yaw damper operation position?

7 THE WITNESS: There is a yaw damper position
8 indicator and it indicates the position of the yaw
9 damper piston electrically. I believe it's an
10 electrically driven indicator in the cockpit, yet.

11 And again, I'm not sure if that's basic or a
12 customer option. I believe it's basic.

13 MR. PHILLIPS: In later testimony we were
14 planning to talk about a series of yaw damper upsets or
15 events over the last few years. Can you speak in
16 general terms of your knowledge of those upsets and
17 events?

18 THE WITNESS: I understand there has been a
19 number of upsets. Most of the upsets have probably
20 been classified as nuisance things. There have been
21 some where people have sent in reports.

22 For the most part we've had dirty, noisy or

1 otherwise rough output, electrical output rate gyros,
2 that give an erratic electrical signal. So what you
3 get is probably a quivering or probably a lot of the
4 complaints have been that the yaw damper is not working
5 very good and doesn't damp the Dutch rollout. And it's
6 of course, a right quality, and if the airplane is
7 bouncing around in turbulence, we get write-ups from
8 that, too.

9 MR. PHILLIPS: Are you aware of any claims of
10 the yaw damper moving the rudder beyond it's three
11 degree limit in this airplane?

12 THE WITNESS: The answer is no. The yaw
13 damper piston is mechanically limited to what it can go
14 to, and that's that.

15 MR. PHILLIPS: Going to the standby system
16 that you described earlier, could you -- the term
17 galling needs to be defined. Could you please give us
18 a description of what galling is and what it's effects
19 may be to the standby input system?

20 THE WITNESS: When two pieces of metal are
21 rubbed together, the little microscopic peaks kind of
22 rub the tops off each other and eventually when you do

1 this enough you get metal transferred between the two
2 pieces.

3 Not being a metallurgist, I'm not sure
4 exactly what the official thing is, but I think we've
5 all seen on our cars, working on our cars, we have a
6 cap that's rotating in a bushing or something and we
7 get this scratched and rough surface on the shaft.
8 That would be galling. It's really the two pieces
9 rubbing against each other, riding together, breaking
10 loose, riding together, breaking loose and causing a
11 very rough surface.

12 So that's what galling is to my
13 understanding.

14 MR. PHILLIPS: Okay. And on the input
15 bearing or the input shaft of the standby actuator,
16 what would be the effect of galling? What could be the
17 effect of galling for that system?

18 THE WITNESS: Eventually if one were to do it
19 long enough, I guess the galling could get to the point
20 where the two parts wouldn't rotate any more. What we
21 have found a couple of times and several times in
22 service, and we looked at this extensively on a past

1 problem, is that as the galling starts to progress, you
2 start to get a resistance to motion and that resistance
3 to motion, looking at the standby package as the
4 housing moves back and forth, the input link if there's
5 no pilot input stays stationary, and so that link would
6 move back and forth with respect to the housing.

7

8 It's a rotary joint and as that rotary joint
9 gets sticky or has high friction, eventually if you had
10 high enough friction it would start to backdrive the
11 input crank and start to be loaded by the field and
12 centering unit. And the field and centering unit then
13 would at some point, depending on how much stickiness
14 is there, would break the stickiness loose and cause
15 the input crank to return to neutral. And that could
16 very well cause very small rudder motion as this thing
17 is progressing along and this galling comes up, causing
18 the field and input centering unit to kick in and out
19 of center, so to speak.

20 MR. PHILLIPS: Are you aware of any
21 conditions in the accident airplanes that we've been
22 investigating that galling was found on that bearing?

1 THE WITNESS: Yes. 585 was galled and that
2 particular airplane, it was galled and at the same time
3 the input nut was backed off 30 degrees. What we
4 believe happened there was as this lever moved back and
5 forth and the galling progressed to some particular
6 point, we believe -- I believe at least that the main
7 rudder package was probably removed. The rudder was
8 moved to one side, which is about 30 degrees. The
9 galling was pushed into an area where it wasn't working
10 on a daily basis; stuck; and then when the main package
11 was reinstalled, the nut unscrewed.

12 Then after that, the indication that we had
13 on another airplane that we found in service with a nut
14 unscrewed, the nut just screwed in and out and operated
15 perfectly normal.

16 And I guess you're also wanting to know if we
17 had galling on 427. The answer is a small amount of
18 galling. I compared the pictures between 427 and 585
19 and the series of test samples that we ran to
20 investigate 585, and the amount of galling was very,
21 very much smaller than what I saw on 585.

22 My understanding is that when the 427 package

1 was tested, we were you might say fortunate that the
2 rudder system was in the fin and the fin broke off and
3 was outside the fireball, so we had pretty complete
4 pieces there. That package had less than a half a
5 pound friction in it, and a half a pound is the limits
6 for a brand new package.

7 So I would have expected that package to be
8 operating totally normal.

9 MR. PHILLIPS: What would the effect of
10 galling be in the system if you were to run into it in
11 the normal course? Would it make an input to the
12 rudder or would the pilot know that it was galled?

13 What conditions would it take for a pilot to
14 realize that the airplane was in that condition?

15 THE WITNESS: We had several cases in 1986
16 and the write-ups turned out erratic steering, which is
17 basically high friction in the rudder peddles. The
18 pilots could feel it and had some complaints of erratic
19 yaw damper. And it's kind of difficult to really say
20 what erratic yaw damper is.

21 For the most part, I believe it's small
22 inputs that they don't expect in smooth weather or

1 probably rough rides when they expect the yaw damper to
2 take the turbulence out in heavier weather. That's how
3 the ones that we found have been written up.

4 MR. PHILLIPS: Could you characterize what
5 may cause the galling? You described it as peaks
6 rubbing and contacting each other. What would cause
7 the galling?

8 THE WITNESS: Didn't bring a picture of it,
9 but it's a shaft and a bushing and it's hard stainless
10 steel and a relatively soft stainless steel
11 combination. Harder shaft than is the bushing, I
12 believe.

13 Generally speaking, if you have a soft
14 material and a hard material, you typically don't get
15 galling very much. If you have two hard materials or
16 two soft materials you can get galling quite readily.

17 What we have on this package is fairly tight
18 clearances, 2 to 4 ten-thousandths of an inch diametric
19 clearance. We found when the parts were invested in
20 1986 that we had parts that were slightly out of
21 tolerance or when you're trying to hold something
22 within one ten-thousandths of an inch diameter, it

1 doesn't take much of a lump or out of round to fill up
2 that clearance, drive the two parts together.

3 We found that for the most part, although
4 it's not universally true, that parts that galled were
5 quite low time parts that were discovered early in the
6 service life, within a couple thousand hours. Not all
7 of them, but most of them.

8 I guess we had one other case where you could
9 screw the nut in and over-torque it and work it, and
10 that would take up the clearance. In fact, that's how
11 we managed to do our test parts, the testing that we
12 did for it. Reduce the clearance and over-torque it
13 and get the two parts to rub against each other.

14 MR. PHILLIPS: On the subject of
15 contamination or particulates in hydraulic fluid, could
16 you characterize or describe any testing that's done or
17 any specifications that control contamination limits in
18 hydraulic fluid and the effects on the system?

19 THE WITNESS: The procurement specification,
20 which we call BMS3-11, defines the cleanliness level
21 for brand new fluid. We have an internal Boeing
22 specification that we use to check the cleanliness of

1 airplanes before we send them out the door, and also to
2 check our hydrant systems to make sure the hydrant
3 systems stay clean.

4 There's been a lot of sampling done on 427.
5 I think a later engineer has direct knowledge of those
6 exact samples and can give you more data on exactly
7 those samples.

8 MR. PHILLIPS: Is contamination a design
9 consideration in the original design?

10 THE WITNESS: Maybe we can start and talk
11 about a hydraulic system and why you put filters and
12 where you put them.

13 MR. PHILLIPS: That would be fine.

14 THE WITNESS: Okay.

15 If you think of a hydraulic system in
16 general, you have a power source which is a pump. The
17 pump is a piece of rotating equipment. Rotating
18 equipment wears out, has wear particles. And so we
19 start with putting a filter on the outlet of the pump.

20 That filter on Boeing airplanes is a 15
21 micron filter. Since we're going to talk about
22 microns, why don't we throw something up to kind of

1 identify what a micron is to start with.

2 Foil number 11.

3 (Pause.)

4 To get an idea when we're talking microns and
5 cleanliness, there will be a lot of discussion about 10
6 microns, 20 microns. How big a piece is this thing?

7 A micron is 39 millionths of an inch. It's an
8 awfully tiny thing. If you compare it to something
9 that we have a basis for judgment on, say human hair,
10 if you look at the outer circle, that would be a human
11 hair. If you look at that little dot down there,
12 that's a micron.

13 When we talk about contamination and
14 cleanliness, we keep our systems so clean that what
15 we're talking about are these minute little dots. I've
16 heard it described as if you see the dust floating down
17 on a sunbeam, you're talking about stuff that's that
18 small and smaller. We keep the systems very, very
19 clean.

20 So, when you talk about a micron, that's what
21 we're talking about. You can see it on the screen.

22 It's a pretty tiny thing.

1 Incidentally, if you get down and filter the
2 fluid in a 2 to 3 micron range, you actually can filter
3 the coloring dye that's in the fluid out. It's that
4 fine.

5 So, back to hydraulic systems. The general
6 idea is to arrange your hydraulic systems in such a
7 fashion that you get rid of the wear particles. You
8 collect the wear particles, put them through a filter,
9 and arrange your system such that wherever wear
10 particles are generated, you collect them and get them
11 in a return system.

12 So you start with a pump. The pump can
13 generate wear particles. You put a filter on the
14 downstream site of the pump, take the filter fluid, put
15 it into a piping distributor system, a pressure system,
16 take that fluid and drive it back to a component, a
17 critical component, such as flight control packages.

18 We put a filter in the inlet of the package
19 and that's there to make sure that even if there's
20 something introduced into the system say during
21 maintenance when you have a piece of plumbing apart,
22 that you can catch that contamination.

1 Then in the various components, we arrange
2 the flow passages such that wear particles generated
3 within the various components go into a return cavity.
4 The return cavity collects the wear particles, pushes
5 them out into -- just flushes them, I guess I should
6 say -- out into the return plumbing.

7 The return plumbing flows back to the main
8 system filter which we use to keep the system primarily
9 clean. And then we put check valves in various parts
10 in the return line so that you can never run backwards
11 and get any wear particles going back upstream. It
12 always has to move downstream.

13 We collect the wear particles in the return
14 filters, put the fluid into a reservoir storage place
15 for extra hydraulic fluid. From there, put it back
16 into the pumps and recirculate the system.

17 So, the filtration starts out with find a way
18 to collect the wear particles; take care of the various
19 sources where the wear particles are generated; collect
20 those things; get them back to the return system; take
21 them out.

22 We manage the cleanliness of the airplanes by

1 the micron level of the filters. The pressure filters
2 outside the hydraulic pumps are 15 microns. The K-
3 string filters, which is the cooling pumps, is 25
4 microns. I guess 25 microns is what we have at the
5 inlet of all of our flight power control packages on
6 this airplane.

7 MR. PHILLIPS: I think we're going to hear
8 some testimony later on that in some of the fluid
9 samples collected from the accident airplane that we
10 found some particles in the 25 to 100 micron range.
11 What would be your explanation of finding those
12 particles in the area of the power control unit that
13 they were collected from?

14 THE WITNESS: Well, again, the data that I
15 looked at, the particles, the lion share of the
16 particles, were in the return cavity where wear
17 particles within the package that come off are
18 collected in a return cavity and then flushed on back
19 to the return system. So in the return cavities and
20 the linkage cavities, that's where one would expect to
21 find the various wear particles.

22 And again, a 50 micron chunk of wear particle

1 is an awfully teeny, tiny thing.

2 MR. PHILLIPS: Going back to maybe before the
3 original design was conceived, can you describe some of
4 the Federal Aviation Regulations that define aircraft
5 systems design in view of systems failures, jams and
6 what general protections are designed into the airplane
7 to counteract those?

8 THE WITNESS: The 727 I think was probably
9 the last airplane under the Civil Aviation regulations,
10 the CAR's. I think the 737 was probably the first
11 airplane. And as I recall -- it's been a long time --
12 the airplane had to be good for any single failure and
13 the airplane had to be tolerant of jams in the various
14 systems and flight controls.

15 MR. PHILLIPS: The 737 had a failure analysis
16 performed during certification or prior to
17 certification. Are you familiar with that analysis?

18 THE WITNESS: Yes, I am.

19 MR. PHILLIPS: And in the case of loss of
20 control of rudder surface, are you aware of what the
21 failure analysis showed or what the resulting action
22 would have been to overcome that failure?

1 THE WITNESS: As I recall, it indicated that
2 if the rudder becomes inoperative, use a lateral
3 control. And we've had a lot of discussions on the
4 tradeoffs of using lateral versus rudder.

5 MR. PHILLIPS: So in the event of a fully
6 displaced rudder, displaced to the blowdown limit, the
7 pilot would be expected to use the lateral control
8 system to overcome that?

9 THE WITNESS: That's what the failure
10 analysis said. Yes.

11 MR. PHILLIPS: And I believe in that document
12 there's also some discussion of disabling hydraulic or
13 flight control systems related to the hydraulics.
14 Would that also be an alternative to the runaway
15 position or hardover position?

16 THE WITNESS: I think you get into a
17 situation where that's an alternative that's possible,
18 but you start depending upon somebody analyzing and
19 analyzing properly and only turning off the systems
20 when it's the right failure. To misanalyze the failure
21 or situation that they're in and turn off the flight
22 control systems would not be a recommended thing, I

1 don't think.

2 MR. PHILLIPS: Then if I can restate what
3 you've just said, the lateral control exists to
4 overcome the hardover rudder position and that although
5 it may be an alternative to disable the hydraulic
6 system, in your opinion it wouldn't be a recommended
7 procedure.

8 THE WITNESS: As I alluded to earlier, the
9 manual reversion forces to fly the airplane without any
10 hydraulic system are considerably higher than the
11 standard field forces in a normal situation. It would
12 be an unusual situation. It would be something
13 different than guys do on a daily basis. And I think
14 in the long run, I guess I would feel that looking at
15 the probability of misanalyzing a system and going to
16 manual reversion when it wasn't necessary is not a
17 recommended thing to do.

18 MR. PHILLIPS: Do you have anything to add,
19 any other statement you'd like to make or what you'd
20 like to discuss?

21 THE WITNESS: As far as the control system?
22 There is one foil that we brought that we didn't get

1 into. There's been a lot of discussion on
2 contamination of the valve and you alluded to it
3 earlier.

4 If we can show number 12, chart number 12.

5 (Pause.)

6 There's been a lot of discussion in the
7 investigation on this about fine particle contamination
8 and is it a situation that we need to perhaps increase
9 our filtration or do something else about.

10 If you look at a typical slide and sleeve
11 valve, a typical slide and sleeve valve is a steel
12 cylinder inside of a hollow -- just a rod inside of a
13 cylinder. And these things are very, very close
14 tolerance, very tight fit. A typical diametral
15 clearance on a lapse slide and sleeve valve would be
16 anywhere from 80 millionths to maybe as much or two or
17 three thousandths of an inch. But 80 to 200 millionths
18 is very typical.

19 Now that turns out, if you look at it, is
20 like 1-1/2 maybe as much as 2 microns. Now a valve
21 has what we call an underlap, and the underlap a space
22 that's about 25 microns, about a thousandths of an

1 inch, where we interconnect both sides of the cylinder.
2 And that allows us to change what we call the flow gain
3 in a very small part of the performance characteristics
4 of a valve, and that gets into the servo analysis of
5 why you want to do that.

6 But what it does do is it creates
7 fundamentally an open hole and that open hole is about
8 25 microns wide and in a plane it would be
9 perpendicular to the paper. It would be as wide as the
10 metering slot. And on this particular valve, that's
11 about 14 thousandths, as I recall. So you have a
12 pretty sizable hole. And so these 10, 20, 30 micron
13 pieces of material with 3,000 psi upstream, you can see
14 quite readily that they would be pushed right through
15 that open hole into the downstream with a minimum of
16 1500 psi driving them through.

17 We don't see that kind of small particle
18 contamination jamming a valve or sticking a valve.
19 What jams a valve is rust, perhaps, corrosion products.

20 We had an airplane, an Air Force airplane once upon a
21 time, that was serviced with water and the parts all
22 rusted. We had to change everything out in the

1 hydraulic system and flush it.

2 For a large particle -- when I say a large
3 particle, I'm talking about something that's big enough
4 to go into the flow passage, into the metering slot,
5 and wedge in there and stay and not flush on through.
6 A piece of block wire, we've had a couple of shocking
7 bolts, things like that.

8 So, we have found that over many, many years
9 that small particle contamination is not a problem with
10 side and sleeve valves. That we need to be concerned
11 about the large particle contaminations. And as I said
12 before, that happens about once every 10 million hours
13 because occasionally something is left in the package
14 when it's manufactured or introduced during maintenance
15 or some other -- who knows where they come from -- from
16 time to time.

17 So once every 10 million hours we may get a
18 large particle jamming a valve and that's where the
19 dual valve comes in. If the primary would jam, the
20 secondary would override it and perform its function.

21 MR. PHILLIPS: Are you aware of a dual slide
22 concentric valve in a Boeing aircraft design or Boeing

1 aircraft for an airplane, jamming and resulting in a
2 loss of control or loss of function of the system?

3 THE WITNESS: Not losing control of the
4 system. In each case that I'm aware of, the valve has
5 performed precisely as it's been expected to do.
6 Certainly if it's not expected and people don't
7 recognize what it's supposed to do -- I've heard that
8 the thing doesn't work, but in reality we've had like I
9 said, a lot of shocking balls. We had one rusted part
10 and we've given you a couple of service reports and the
11 valve performed its function exactly as it was intended
12 to.

13 MR. PHILLIPS: Would these failures be
14 obvious to the flight crew?

15 THE WITNESS: I believe they would.
16 Remember, I said the function is to dump the package,
17 dump the pressure, depressurize the package. But in
18 certain cases it would provide full hinge moment at
19 that rate. And so in any case except -- well, let me
20 put it one way. If it jammed in the extreme of travel
21 where the surface was dead and that could be written up
22 as rudder peddle jam is one of the ones that we had,

1 and the reality, the valve was bypassing fluid and
2 didn't respond. Very obvious.

3 In the other extreme, if it jammed in primary
4 and neutral and it was being overridden by the
5 secondary where you actually had performance out of the
6 valve, you'd get full hinge moment capability at 50
7 percent travel and any jam in between you might get 20
8 percent hinge moment at 20 percent rate. And those
9 things would be detectable in a control check.

10 MR. PHILLIPS: In other testimony we heard
11 some discussion of blowdown. Could you describe what
12 blowdown is from the systems perspective?

13 THE WITNESS: Blowdown is if you look at this
14 rudder package specifically, it's designed to react in
15 air load at a relatively low airspeed to counter an
16 engine out. On this particular airplane it's 100 and
17 some knots. I don't know the exact number any more.
18 And that's how much power we put into the power control
19 package; 3,000 psi times the area of the piston.
20 That's how much torque can be generated on the rudder
21 to react the air loads.

22 As the airspeed goes up, the air resistance

1 goes up, obviously. And what it says is for that
2 amount of torque that we built in, you can only deflect
3 the rudder a limited amount so that it creates the
4 torque that the package -- react the torque that the
5 package can produce.

6 So, at 110 or 115 knots, whatever it is, you
7 get full rudder travel at 3,000 psi differential across
8 the pistons. At 300 knots you'd get considerably less
9 amount of rudder to recreate that same amount of
10 torque.

11 MR. PHILLIPS: Is that something that just
12 happens in the design or is it on purpose to designed,
13 the area the pistons control for blowdown?

14 THE WITNESS: On this airplane we have made
15 the pistons as small as we possibly could to handle the
16 engine out at low speed because if you look at the
17 design of the body bending moment in the fin, the
18 bigger the package is the more metal you have to put in
19 the body for body bending loads. And so it's to our
20 advantage to make the package as small as possible and
21 that's what we do.

22 MR. PHILLIPS: And one last question on the

1 main rudder power control unit. Is the design similar
2 for all 737 series aircraft? Could you briefly
3 describe the differences between the 100, 200, 300 and
4 400?

5 THE WITNESS: The 100 and 200 came out with
6 two sets of yaw damper pistons. The 727 which is just
7 before this airplane, required an operable yaw damper
8 if you were flying at some altitude and speed. The 737
9 had two yaw dampers because the same people did the
10 design and if you needed it once, you put it in the
11 next airplane. And that's the best guess that the
12 people that did the wind tunnel testing had at the
13 time.

14 In flight tests, it turns out the airplane
15 was quite stable, did not need dualization on the yaw
16 damper for Dutch roll damping and so at some later
17 point in time, -- I can't remember exactly when it was.
18 I think I may have some notes.

19 (Pause.)

20 In about 1974 we took out the second yaw
21 damper piston because it had just been going along for
22 the ride. So at some point in time we took out the

1 electronics and went to a single package.

2 So we have packages that have two yaw
3 dampers, one of which isn't hooked up to anything. It
4 just sits there because there's no electrical system in
5 the airplane any more. We have later packages with a
6 single yaw damper package. And then over a period of
7 time we have packages with different amounts of
8 authority.

9 We have 2 degrees, 4 degrees, and today we're
10 back to 3 degrees.

11 MR. PHILLIPS: And who provides that main
12 rudder power control unit to Boeing?

13 THE WITNESS: The main rudder power control
14 unit is designed on Boeing paper with exception of the
15 servo valve, which is a vendor proprietary item. And
16 the package is procured from Parker Hannifin.

17 MR. PHILLIPS: And the standby rudder
18 actuator supplier?

19 THE WITNESS: The standby rudder package is
20 procured under a procurement specification. It's a
21 vendor designed item that we buy under specification.
22 And that's from Dowdy Aerospace, Los Angeles.

1 MR. PHILLIPS: I've got no further questions.

2 CHAIRMAN HALL: Do any of the parties have
3 questions of this witness? Anyone other than the
4 Boeing Corporation?

5 If not, Boeing, please proceed.

6 MR. MCGREW: Thank you, Mr. Chairman.

7 Mr. Turner, the only question I have is are
8 you totally satisfied that the amount of galling in the
9 load seen at the actuator -- the standby actuator,
10 would absolve it from any participation in the 427
11 event?

12 THE WITNESS: There's no doubt whatsoever.

13 MR. MCGREW: Thank you, Mr. Chairman.

14 CHAIRMAN HALL: Thank you.

15 Mr. Marx?

16 MR. MARX: I'm interested in that last answer
17 to the question having to do with galling. My
18 understanding is in your testimony here, anyway, is
19 that some yaw damper irregularities that have occurred
20 in the past can be traced back to what you feel to be
21 galling in the standby rudder. Is that correct?

22 THE WITNESS: We had one case in 1986 that

1 had erratic yaw dampers. I believe it was -- the write-
2 up, the only thing we found was gall packages -- gall
3 in the fluid drain.

4 MR. MARX: And is it possible for the
5 freezing of the standby rudder by galling, which may be
6 temporary or what have you, to cause the rudder to move
7 past the three degrees from the yaw damper input?

8 THE WITNESS: Past three degrees?

9 MR. MARX: Yes.

10 THE WITNESS: Just because of the yaw damper
11 input?

12 MR. MARX: Well, we know that the yaw damper,
13 based on your testimony, will be limited to plus or
14 minus three degrees, a total of six degrees. And if you
15 have galling that occurs in the standby unit, let's
16 just say that we have a frozen unit up there. How far
17 is it possible to drive the rudder?

18 THE WITNESS: We have done some calculations
19 of that and you get different answers depending on what
20 assumptions you make on spring rate; what assumptions
21 you make on how much friction; whether the thing
22 springs back; whether it's forced back.

1 What we have seen in our calculations is
2 static offsets at -- say, for instance, the report that
3 you have of 60 pounds where the thing is galling to the
4 point of 60 pounds, the field and centering unit would
5 cause that galling to break loose. It provides enough
6 force to break that galling loose in the 2-1/2 to 3
7 degree, as much as perhaps 4 degrees, depending on the
8 amount of friction in the system.

9 If you were to say is it conceivable that
10 this thing could stick, the yaw damper could put in
11 input, cause this 2 to 2-1/2 degrees offset, the
12 airplane yaw in the other direction, the yaw damper
13 reverse direction and get those things attitude, that
14 could very well be. I have no way of knowing that for
15 sure.

16 MR. MARX: I don't quite understand. You're
17 saying that it can move past 3 degrees?

18 THE WITNESS: In a dynamic overshoot
19 situation, I wouldn't be surprised.

20 MR. MARX: Well, how far past 3 degrees could
21 it be moved?

22 THE WITNESS: Our simulations would indicate

1 that a typical -- depending on the assumptions you make
2 -- could be 4-5, maybe 6 degrees. That's my
3 recollection. I think you have a report from 585 on
4 that.

5 MR. MARX: You were also making some
6 statements about hard and soft materials and the effect
7 of galling. Is there anything else, such as high
8 contact pressures that could produce galling?

9 THE WITNESS: Well, obviously the parts have
10 to be rubbing against each other, but again, I'm not a
11 metallurgist so my perception of galling is two parts
12 that are rubbing against each other. If they are of
13 similar hardness, if they're not lubricated, then the
14 harder you push them together the more likely they are
15 to gall.

16 MR. MARX: Well, I happen to be a
17 metallurgist so I do know a little bit more about it.
18 What I'm trying to get across here is that if you have
19 two materials that come together and produce galling
20 and galling is a result of something that can be
21 produced by high contact stress, could that high
22 contact stress be signifying some other problem that is

1 occurring in the shaft and bearing?

2 What I'd like to do also is go a little bit
3 into where this galling occurred on this particular
4 shaft. Do you know whether galling occurred?

5 THE WITNESS: I've seen the pictures. Yes.

6 MR. MARX: And was it in the same location as
7 that that occurred on Colorado Springs?

8 THE WITNESS: No. Colorado Springs occurred
9 in the unlubricated part of the shaft outside of the
10 seal, and this one occurred on the inside.

11 MR. MARX: On the lubricated portion, would
12 you expect to have higher contact stresses because you
13 are in the lubricated portion to produce galling or
14 versus the one that occurs in the unlubricated portion?

15 THE WITNESS: The speed of rotation is so
16 slow on that thing. I'm not sure that it would be a
17 lot of difference on the things.

18 MR. MARX: Well, what is the speed rotation
19 on it?

20 THE WITNESS: The thing moves back and forth
21 approximately 2 degrees and it would move at -- depends
22 on how hard you kicked the rudder peddle. Probably 30

1 degrees per second or something like that.

2 MR. MARX: This is the -- you're talking
3 about the rotating of the shaft with respect to the
4 bushing?

5 THE WITNESS: The bushing to the bearing.

6 MR. MARX: What's to keep a bound up from
7 galling on the standby unit from running away or
8 causing the main PCU to run away?

9 THE WITNESS: The torsional compliance in
10 that area, if it tries to drive the system, it starts
11 to lift the field and centering cam up out of the
12 detended position. That loads that compliant link and
13 that part bends, rotates, gives up. And that allows
14 and actually puts a signal into the main rudder package
15 to stop the motion.

16 MR. MARX: And this was established as a
17 result of the investigation that was done in Colorado
18 Springs?

19 THE WITNESS: No. It was really investigated
20 thoroughly in our iron bird testing in either 1967 or
21 1968, which was the reason that we were able to take
22 the shear-out mechanism out of the linkage, which was

1 put in there for protection against that particular
2 failure mode. The shear-out didn't work because of the
3 compliance, so it was inherent in the system.

4 MR. MARX: I'm not too sure -- I didn't
5 follow that, what you were talking about on the shear-
6 out. Could you explain that one more time?

7 THE WITNESS: When we designed the airplane
8 way back when, you may recall we said we had to be good
9 for any single failure, including any jam, bind, valve
10 jam, whatever, in the standby package. And we put a
11 shear-out in there, so that one could put your feet on
12 the rudder peddles and cut the shear out and release
13 that from the rest of your system and regain normal
14 control.

15 That shear-out wasn't needed because of the
16 softness in the torsion link that travels between the
17 main package and the standby package, and the torsional
18 capability of that part negated the need for the shear-
19 out. It simply wound up so much that we couldn't cut
20 the shear out.

21 MR. MARX: During normal yaw damper
22 operations, the yaw damper is moving back and forth to

1 cause the rate of change movement on the main PCU,
2 which is the primary and secondary valves.

3 What is the maximum rate that the yaw damper
4 can move that rudder? I'm talking about in degrees per
5 second.

6 THE WITNESS: I'd have to look it up, but I
7 believe that it can run at about 30 or 40 degrees per
8 second maximum rate, maximum yaw damper rate.

9 MR. MARX: Why can't it do the full rate
10 travel of -- what is the normal? If the pilot input
11 into the rudder peddles the maximum rate he could do,
12 what would that cause in the main PCU? How fast would
13 the rudder move?

14 THE WITNESS: Let me see. I haven't looked
15 at this package this close for several months.

16 (Pause.)

17 Typically, we set the rate of augmentation
18 systems by sizing the mod piston, the yaw damper
19 piston, with respect to the flow rate of the transfer
20 valve. The transfer valve gives you about three-tenths
21 of a gallon a minute and I don't remember what the area
22 of the mod piston is.

1 Relying on memory, I don't know what the area
2 of that is. But that would say how fast the mod piston
3 could move. The mod piston has enough stroke to
4 certainly drive the rudder package to its maximum rate.
5 If that area is small enough to be saturated at three-
6 tenths of a gallon a minute, I guess it could run all
7 the way up to maximum travel.

8 My recollection is it's a little less than
9 that, maximum rate. My recollection is a little -- I
10 may be wrong on that. It's been a long time since I
11 looked at it.

12 MR. MARX: I think from what I hear from you
13 is that you're telling me you're not actually sure but
14 you think it could go to full maximum rate, but you're
15 not sure. Sometimes you think it may --

16 THE WITNESS: Let's make an assumption it can
17 go at 56 degrees per second.

18 MR. MARX: And what would be the maximum?

19 THE WITNESS: Then where would we go?

20 MR. MARX: If the maximum rate -- in other
21 words, can we take and move the -- in the yaw damper,
22 the question would be can the yaw damper move the

1 secondary as far as it can move to its full travel?

2 THE WITNESS: The yaw damper is capable of
3 moving the primary and secondary to the valve stops;
4 yes, to the external valve stop. In a normal
5 situation, there's no doubt in my mind that the yaw
6 damper piston itself can stroke at three-tenths of an
7 inch, roughly three-tenths of an inch. It's enough to
8 drive both primary and secondary to the valve stops,
9 yes, the external valve stops.

10 MR. MARX: And what about the internal valve,
11 internal stops?

12 THE WITNESS: The only way you can drive the
13 secondary to the internal valve stops is to have a jam
14 of the primary to the secondary so that you have a
15 direct load path without going through the secondary
16 linkage.

17 MR. MARX: Okay. I think I'll probably ask
18 some questions later on though when we get to some of
19 the other people, but I was just trying to get a --

20 CHAIRMAN HALL: Can we -- in an attempt to
21 follow this conversation, do you think we could put
22 Exhibit 9-S back up there, page 7? And you could

1 explain the operation of this yaw damper to us one more
2 time.

3 THE WITNESS: Chart 7 you say? Okay.

4 CHAIRMAN HALL: If I understand what we're
5 trying to do is find out how far this thing can move;
6 right?

7 MR. MARX: Right. I realize that it's a very
8 complicated subject and --

9 CHAIRMAN HALL: No. I don't have any
10 problems. That's what we're here for is to get into
11 complicated subjects. But I thought it would be
12 helpful because I'm having difficulty following it.

13 MR. MARX: Well, don't feel bad at all about
14 that.

15 (Laughter.)

16 It took me a couple of days before I got it
17 straightened out.

18 THE WITNESS: There's little doubt that it's
19 extremely complicated, and this particular picture, I
20 might suggest we could talk for an hour and it would
21 probably still be confusing. There's a later video
22 coming on in Paul Cline's presentation and the video

1 has this thing laid out in a cavia model, a 3-g type
2 cavia model where you can actually see the motions of
3 these internal summing levers. And it might help to
4 get a better picture.

5 Just to give you an idea of what you would be
6 seeing, could you put up the next chart, chart number
7 8?

8 CHAIRMAN HALL: What part of that limits the
9 yaw damper's movement?

10 THE WITNESS: See the area that says -- up
11 near the top of the page, it says Yaw Damper Actuator?

12 CHAIRMAN HALL: Right.

13 THE WITNESS: That's a steel cylinder that
14 moves inside of a bore, and that's the yaw damper
15 actuator. And it's a spring cage to a neutral position
16 and -- why don't we try the next chart, and this will
17 give you an idea of what you're going to see in a video
18 that's actually a moving video.

19 As you can see, there's a multitude of parts
20 there. The upper piston, you can see that that upper
21 piston has a limited stroke. It can only move within
22 the bore that's available to it. And that's the yaw

1 damper actuator and while it's going to be awfully
2 tough to see in this two-dimensional picture, when you
3 get to the moving simulation, what you can see is that
4 the yaw damper piston servo system, if you put a
5 command, everything starts to happen. But if you break
6 it down one piece, you put an input in and then this
7 happens and then this happens. And take it one step at
8 a time.

9 You can see that the yaw damper piston, if it
10 moves, it will move what we call the internal summing
11 links. And the internal summing links would pivot
12 about Point B. Those would move the servo valve and
13 the servo valve at that point would be porting fluid to
14 one side or the other of the main power piston.

15 And the main power piston, this big thing up
16 on top that says piston, would then respond and would
17 move. When that moves, the bottom part of the summing
18 lever is fixed. It's connected to the pilot's rudder
19 peddle, so it doesn't move. And what happens then is
20 as the top end of that big lever moves, it moves a
21 thing called a valve crank, which is like -- the
22 external summing link, I guess, is the way it's

1 labeled, which drives the input crank that rotates and
2 literally moves Point B over. And those motions add up
3 to read all the valves, so that the valve goes back to
4 neutral and the piston stops moving.

5 Within that complicated linkage train, the
6 piston is obligated to -- output piston is obligated to
7 move in a direct proportion to the amount of stroke of
8 the yaw damper and the linkage ratios of all these
9 summing levers.

10 CHAIRMAN HALL: The yaw damper moves without
11 the pilot? Doesn't require the pilot's input; right?

12 THE WITNESS: That's right.

13 CHAIRMAN HALL: This is an electrical --

14 THE WITNESS: This is a series mode. And
15 within the authority of the yaw damper actuator it will
16 move. And the input point will not move for those three
17 degrees.

18 CHAIRMAN HALL: And it's basically moving all
19 the time in flight or a lot, part of the time?

20 THE WITNESS: It tends to move -- cycle, at
21 the natural Dutch roll frequency of the airplane.

22 CHAIRMAN HALL: And what is the life of a

1 unit like that?

2 THE WITNESS: The whole power control package
3 being a hydraulic device with teflon and rubber seals
4 in it, 20,000 hours is a pretty good life on a piece of
5 hardware like this.

6 Generally, the moving parts, the metal parts,
7 don't wear out as rapidly as the seals, the soft parts.
8 And so the typical thing you do on hydraulic equipment
9 is monitor the leakage, and when it starts to leaking
10 quite a bit, whatever the airline elects to put as
11 their criteria -- and we've got some recommendations
12 for that. When it gets to leaking to the point they
13 want to change it, then they schedule maintenance and
14 change it.

15 Now, we put in teflon cap strips on the seals
16 so that when it starts to leak, it starts to dribble,
17 and then more and then more and more, rather than the
18 other failure mode of a pure rubber seal is it's real
19 dry and all of a sudden it goes -- atchoo.

20 The long life seals that start to dribble and
21 dribble and dribble allows a maintenance operation to
22 schedule maintenance on it.

1 CHAIRMAN HALL: I'm sorry, Mike. Proceed
2 ahead. I didn't mean to butt in, but --

3 MR. MARX: I think that maybe some of the
4 other technical questions we could ask to the other
5 witnesses that come in. I was just trying to get your
6 feel for it because of the amount of experience that
7 you have with these units.

8 If you could just give me some ideas as to
9 why you answered the question that the Boeing
10 representative asked you about the galling. I think
11 the question was to the effect that this galling could
12 have had absolutely nothing to do with the movement of
13 the rudder. To that extent, could you go a little bit
14 further into that?

15 THE WITNESS: The testimony that we've heard
16 so far indicates a rudder motion that comes in roughly
17 5 degrees per second to a full blowdown position. If
18 it were the rudder, and that's what people have been
19 discussing, bringing something in at a particular rate
20 like that is not the characteristic at all of having a
21 gall package. A gall package, the stroke would be
22 considerably less. The field and centering unit would

1 break it out at some small amount of rudder.

2 As a matter of fact, this one actually
3 measured half a pound, less than half a pound. And at
4 less than a half a pound, that's way, way -- that's
5 smaller than what the field and centering unit can
6 handle.

7 And in any case, the field and centering unit
8 alone, with no input from the rudder peddles at all, no
9 corrective action at all, the field and centering unit
10 would prevent this thing from every going -- what did
11 we have? 16-18 degrees? Whatever the chart showed.
12 There's too much compliance in the system for that.

13 And this thing went over at a relatively
14 constant rate, an average rate of 2-1/2 to 5 degrees.
15 That's just not the characteristic that we have seen or
16 would expect to see.

17 MR. MARX: So you wouldn't be able to get the
18 rate of 2-1/2 to 5 degrees with a frozen bearing to the
19 shaft? Is that what you're saying?

20 THE WITNESS: You couldn't get it all the way
21 to the 16 degrees.

22 MR. MARX: No, but how about the rate, 2-1/2

1 to 5 degrees?

2 THE WITNESS: One would have to start to
3 speculate some kind of a thing where -- gee, I don't
4 know what you'd do. Assume that it wasn't stuck and
5 all of a sudden it welded solid at some particular
6 position. That would be pure speculation.

7 MR. MARX: Are you aware that in galling
8 situations you can actually have a very large force at
9 one time and then a very small force resulting from the
10 breakaway or that this connection of the transferred
11 metal or the T welding of the metal as it breaks away?
12 Are you aware that this force, rotational forces, can
13 go down?

14 THE WITNESS: I'm aware of that.

15 MR. MARX: So the one half pound that was
16 measured after the accident may not be representative
17 of the position in which it was actually -- the metal
18 was transferred onto. Is that correct?

19 THE WITNESS: I think that's speculation to
20 draw that conclusion in my opinion.

21 MR. MARX: Okay. Let's put it this way.
22 Have we done any galling tests at all on parts in the

1 past as a result of Colorado Springs?

2 THE WITNESS: Yes. In participation with the
3 Systems Group, they asked us to set up a test, and we
4 manufactured some special parts and created galling,
5 and we'd create galling on a number of samples. What
6 we were attempting to do was to try to duplicate the
7 kind of galling that we saw in Colorado Springs and
8 also match that with the part that we had from 1986
9 where we knew what the galling load was, which was 57
10 pounds on that particular part in 1986.

11 We ran probably six or eight samples and
12 recorded the breakout force, the running torque. And
13 yes, we saw that it tended to be a function of how
14 rapid you moved it. If you'd run it at a fairly slow
15 rate and then you made some larger inputs through the
16 rudder peddle, you had a tendency to get a higher force
17 at that particular point in time, so it's not constant.

18 MR. MARX: It's not constant.

19 THE WITNESS: But we didn't see anything in
20 any of our testing where it was very, very low and then
21 suddenly got very, very high and then suddenly went
22 down to nothing. What we saw was if it was on a test

1 part -- and we took one of these test parts and ran it
2 and ran it and ran it until it was solid, as solid as
3 we could get it, like 120 pounds, it had a tendency to
4 go stick slip, but not from zero to 120 pounds. It was
5 140 to -- you know, it varied but it didn't go from
6 zero to a big number. That's what our test indications
7 were.

8 MR. MARX: Not from zero. I'm talking about
9 from a large number down to a very low number where you
10 have actual sticking of the parts and then that
11 sticking breaks loose and you go down to a low number.

12 THE WITNESS: We didn't see that in the test
13 program that we ran for you at all.

14 MR. MARX: Okay. I don't have the data here
15 in front of me either, so I just wondered what you
16 recalled from that test.

17 THE WITNESS: It changed in value, but we
18 didn't see gross changes of the kind you're talking
19 about. No.

20 MR. MARX: I have no further questions.

21 CHAIRMAN HALL: Mr. Clark?

22 MR. CLARK: I have no questions.

1 CHAIRMAN HALL: Mr. Schleede?

2 MR. SCHLEEDE: Just a couple areas, Mr.

3 Turner.

4 In the maintenance records for this accident
5 airplane, Flight 427, the main rudder PCU was replaced
6 in January of 1993. And I'm not sure if this is in
7 your area of responsibility or expertise, but there was
8 a non-routine work card written for the bolt that
9 attaches the PCU to the rudder, that it found to have,
10 and it quotes, "a slight step worn in it," and the bolt
11 was replaced and shipped back with the PCU, which had
12 been leaking.

13 First of all, are you aware of that
14 information?

15 THE WITNESS: I have read your exhibit.
16 That's the only thing that I personally had to do with
17 it.

18 MR. SCHLEEDE: Do you have any knowledge or
19 experience regarding this type of wear on that
20 particular bolt?

21 THE WITNESS: Well, it's the main pin that
22 went through the main piston into the rudder. What

1 happens if that bolt wears, sometimes under load the
2 pin will rotate in the bushing rather than rotate in
3 the bearing, particularly if you're flying at high
4 altitude and the temperatures are very low and the
5 grease gets stiff in the bearing. And as the pin
6 rotates in the bushing or it could even rotate in the
7 inner recess of the bearing, depending on the fit,
8 those pins wear from time to time, and what you get is
9 backlash. And, you know, in a C check or D check,
10 there's a backlash check.

11 MR. SCHLEEDE: So is this something that you
12 would become aware of in the course of your
13 responsibilities?

14 THE WITNESS: I would have, had I still been
15 in the Sustaining Group. It's the kind of thing that
16 if it's reported, and of course there's a series of
17 legal requirements on reporting. If it's reported, it
18 would come into our Service Group. Our Service Group
19 would monitor those reports and get with the
20 appropriate Sustaining people and we'd take action
21 where necessary.

22 How that process works, I think Mr. Johnson

1 will go over that in a lot of detail. But it's the
2 kind of thing that if we saw very many cases of it,
3 would know about it.

4 MR. SCHLEEDE: Well, you are aware of past
5 instances of that?

6 THE WITNESS: I don't have any -- I can't
7 recall of any other than this particular one, but I'm
8 not a bit surprised. It's just another bolt and
9 another wear part.

10 MR. SCHLEEDE: Would it be possible to point
11 out the location where we're talking about on there?
12 Is it on that diagram?

13 THE WITNESS: I think it's a small picture
14 but -- put the other one back up, please.

15 If you can hit the main rudder control
16 package rod end where it attaches to the -- there you
17 go.

18 MR. SCHLEEDE: Okay. We're on Exhibit 9-S,
19 page 6.

20 THE WITNESS: When I read that report, I
21 believe that's the bolt they were talking about. I
22 didn't spend a lot of time reading the report, but I

1 think that's what they were talking about.

2 MR. SCHLEEDE: I was just curious whether
3 there was -- because in fact it was found on this
4 particular aircraft, is there anything within the main
5 PCU mechanism or any of this other bushrods and so
6 forth that could generate forces to that bolt?

7 THE WITNESS: That bolt takes the full load
8 of the rudder power going into the rudder, so it's
9 loaded every time that you fly the airplane multiple
10 times. And during the certification of the airplane,
11 during the testing, we go in there and put undersized
12 bolts in and see whether there's symmetric backlash
13 that we can get phenomenon on the flutter, which we
14 heard about earlier.

15 So we go into the maintenance manual and put
16 wear and rework limits on that bolt, and so that's a
17 point that we test to see how much backlash can we have
18 there without creating a condition we're concerned
19 about. We put that in the maintenance manual and
20 that's one of the inspection points.

21 MR. SCHLEEDE: What kind of condition would
22 you be concerned about if there was backlash?

1 THE WITNESS: Flutter. If it got too great,
2 you'd have potential for flutter. And it would be
3 plenty times more backlash than what's allowed in wear
4 and rework tolerance area of the maintenance manual.

5 MR. SCHLEEDE: I know you're probably getting
6 tired of talking about standby rudder actuator. If the
7 standby rudder actuator is frozen solid, and I know it
8 wasn't in this accident with 427, but if it's frozen
9 for any reason, galling or the servo valve is corroded
10 and frozen, what effect does that have on the operation
11 of the rudder system?

12 THE WITNESS: You're saying a hypothetical,
13 if you were to put a clamp on there and you couldn't
14 move it?

15 MR. SCHLEEDE: I'm aware of one particular
16 incident, a recent one, which a servo within the main
17 PCU was frozen from corrosion. Now if it's frozen or
18 galled up to a significant value, what is the resultant
19 reaction to this rudder system?

20 THE WITNESS: On that particular one that
21 you're talking about, I believe it's the one that was
22 rusted and the valve had broken off. That's a case

1 there where during -- undoubtedly, during a control
2 check, the housing didn't move with respect to the
3 pilot's input command; broke the ball off. It takes
4 about -- you know, we broke one of those in the 585
5 investigation and it took -- I think it took 75 pounds
6 at the input crank to snap that ball off.

7 So what you would get is this thing would
8 start to backdrive, if you want to call it that, and
9 then the field and centering unit or the pilot's
10 command would create enough load to wind up the input
11 crank or the torque tube and the rudder would offset
12 some small amount. Depends on whether it was jammed
13 directly at neutral or some offset amount. It depends
14 on how far it would go.

15 MR. SCHLEEDE: If you had it in that
16 condition and had a step input on the yaw damper, what
17 would be the result?

18 THE WITNESS: That's where we were talking
19 before of how far it would go. You'd get an erratic
20 yaw damper.

21 MR. SCHLEEDE: Okay. But --

22 THE WITNESS: See, the yaw damper, the

1 control laws, the electric control laws are expecting
2 if the black box put in half a degree of rudder, it's
3 expecting to get the airplane response out of a half a
4 degree of rudder. If it gets more or gets less, then
5 it tries to correct for that electronically, and so the
6 electrons try to do something different, try to correct
7 for something that they can't handle. And it sits
8 there and doesn't cycle at its normal rate. It goes
9 erratic.

10 MR. SCHLEEDE: Okay. I think one more in
11 that area. If the standby is frozen for whatever
12 reason or severely galled up and there's for some other
13 reason a loss of A and B system in flight, is the
14 airplane controllable in that condition?

15 THE WITNESS: That's a triple failure and the
16 answer, the short answer is that the airplane is not
17 capable of handling any number of triple failures, and
18 this is one of them.

19 Now, to prevent that from happening, the
20 hydraulic systems themselves are quite reliable.
21 Having a double failure is a rare event in itself, and
22 we go check the standby system at every C check, which

1 is an appropriate time interval to go check for those
2 latent failures that you're talking about.

3 In that respect, this airplane would meet the
4 same criteria as a brand new 777 for two latent
5 failures or two active failures plus one latent
6 failure. It would be well past that. Extremely
7 improbable.

8 MR. SCHLEEDE: In this case your latent
9 failure would be the standby --

10 THE WITNESS: That's correct. With the
11 recommendation that is a C check. And of course that
12 checks having a disconnect or valve jam or welding or
13 any number of single failures in a single system.

14 MR. SCHLEEDE: Mr. Turner, have you learned
15 anything in your role in the investigation of this
16 accident or the Colorado Springs investigations that
17 gives you concern for any changes that need to be made
18 to the rudder system on the 737?

19 THE WITNESS: One change that we are
20 considering is, since there's been a lot of publicity
21 and we have seen the 427 going, we did make a change to
22 that bushing. Increased the clearance. And what we

1 now see is the galling was outside. It's now inside.
2 And we've got at least this one case of it that I'm
3 aware of.

4 We've been taking a look at what it might
5 take to make another change to that area. And exactly
6 what the change would be, the people involved in the
7 design of it will all talk about.

8 MR. SCHLEEDE: Okay. Well, since you raised
9 that, are you aware that the NTSB made recommendations
10 following the Colorado Springs investigation for
11 periodic check of the standby rudder actuator input arm
12 to detect binding?

13 THE WITNESS: Yes. I've read the proposed AD
14 Note that was put out.

15 MR. SCHLEEDE: And there was a proposed AD
16 note which was withdrawn. Were you involved in the
17 discussions on the decisionmaking to withdraw that
18 notice of proposed rulemaking?

19 THE WITNESS: Not directly any discussions
20 with the FM as to -- that it should or should not be
21 an AD Note. What we did was sit down and discuss the
22 ramifications in the failure modes and created the data

1 to allow the FM to make that recommendation to
2 withdraw it. Which that data was apparently passed on
3 to the NTSB because there's a letter in your file that
4 concurred with that withdrawal.

5 MR. SCHLEEDE: You mentioned the discussions
6 about those changes. Are there any other changes that
7 you're thinking about or working on?

8 THE WITNESS: I can't think of anything that
9 we would do to this system.

10 MR. SCHLEEDE: Thank you very much, Mr.
11 Turner.

12 CHAIRMAN HALL: Mr. Laynor?

13 MR. LAYNOR: Mr. Turner, at the risk of
14 belaboring a point, just a couple.

15 In the yaw damper actuating mechanism, are
16 you aware of any failures at all to the walking beam or
17 the summing levers or anything that can result in a
18 primary servo valve signal?

19 THE WITNESS: We did find a package that came
20 back from one of the airlines that had a summing lever
21 that was not machined properly and it didn't stop where
22 it was supposed to stop on the external valve stop and

1 caused the valve to stroke further than we'd intended
2 for it to, yes.

3 As far as I know, that's the only one of
4 those that's ever been found.

5 MR. LAYNOR: But nothing that would explain a
6 jam of any kind, a failure of the valve to null?

7 THE WITNESS: Repeat that again. I'm not
8 sure --

9 MR. LAYNOR: Any failures because, as I
10 understand that one, that would not prevent the valve
11 from nulling the main servo valve. Is there any
12 failures in that mechanism that would produce a
13 continuously moving rudder to the hardover position?

14 THE WITNESS: Not sure what failures you
15 might be referring to. If you're --

16 MR. LAYNOR: Well, I'm talking --

17 THE WITNESS: If we speculate that there
18 could be some additional parts out there that are mis-
19 machined, one could speculate that, I guess.

20 MR. LAYNOR: I'm just talking about known
21 failures to your knowledge that may or may not have
22 ever occurred to the walking beam or the summing levers

1 or any of that mechanism, any of the freezing of any of
2 the pivot points or anything that would explain a
3 continuously moving rudder.

4 You're not aware of any?

5 THE WITNESS: The only one that I'm aware of
6 in that mechanism is the one we just spoke of that was
7 mis-machined.

8 MR. LAYNOR: And getting back to the
9 possibility of a jammed either primary or secondary
10 servo valve spool, is there any test conducted to
11 determine what the maximum pressure differential that
12 can be developed in any single jam?

13 THE WITNESS: We didn't put a limit on this
14 particular 737 rudder valve on the drawings. There's
15 been some testing done. There's been a tolerance study
16 run. Those test results will probably be examined
17 pretty detailed in later testimony.

18 MR. LAYNOR: Have you personally looked at
19 any of the hardware from the accident aircraft, 427,
20 the summing lever mechanisms and anything to determine
21 whether you saw any anomalies?

22 THE WITNESS: I haven't personally looked at

1 them. Paul Cline is the fellow that's done the lion's
2 share of that.

3 MR. LAYNOR: The only other question to
4 belabor the standby input crank arm a little bit. I
5 was of the understanding that there was an iron bird
6 type of test to determine the compliance in the torque
7 tube and the levers as such. Was I under a mis--

8 THE WITNESS: No. I referred to it as the
9 more formal name of the Flight Control Systems Test
10 Rig. That's our iron bird.

11 MR. LAYNOR: But early in your testimony when
12 you were discussing that in response to Mr. Phillips,
13 you said that it was done by analysis and looking at
14 the elasticity of the parts. Was there actually a test
15 conducted to verify how much force that the centering
16 spring would have to exert to bring the valve back to
17 null?

18 THE WITNESS: At the time of 585 when I was
19 involved in looking at this, the flight controls test
20 rig for the 737 had long since gone away. We didn't
21 have the capability of going out and doing additional
22 testing. There was some testing done in 1967-68. I

1 can't tell you exactly what all went on back there.
2 I'd have to go look it up in the files.

3 But no, we did not, when we reviewed this a
4 couple of years ago, have the facilities to go do that
5 kind of testing.

6 So, at that point, that part of it was done
7 by analysis.

8 MR. LAYNOR: Okay. Do you know of any
9 failures, any type of malfunctions at all in your
10 knowledge of the history of the 737 that have resulted
11 in a rudder hardover?

12 THE WITNESS: There was one case where the
13 airplane on approach had a jammed valve at the steel
14 ball. I can't remember which airplane it was without
15 looking it up. And, of course, if you have small
16 residual pressure even 100 psi on the ground, the
17 surface will move to its extreme of travel.

18 So, that particular airplane had a jammed
19 valve. The secondary did it's job and at slow
20 airspeed, at touchdown, the rudder went to its extreme
21 of travel. The write-up said at 100 knots. Not an
22 instrumented airplane. You can't guarantee the

1 validity of that.

2 It did exactly what it was supposed to do.

3 MR. LAYNOR: Okay. So that was the pressure
4 differential we were talking about earlier without much
5 hinge moment that caused that to move? Is that
6 correct?

7 THE WITNESS: That's correct.

8 MR. LAYNOR: Okay. Thank you, Mr. Turner.
9 That's all.

10 CHAIRMAN HALL: Mr. Turner, first, again, let
11 me thank you for your assistance to the Board and your
12 patience in this testimony this afternoon. I have a
13 few questions, however, and I hope they will be -- by
14 nature they will be less complicated than the ones that
15 you got from Mr. Marx.

16 But is the rudder system that was on the
17 flight, the USAir 427, essentially the same rudder that
18 was on the Colorado Springs flight?

19 THE WITNESS: It's the same rudder system
20 with very minor detail differences on every Boeing 737
21 airplane and every model.

22 CHAIRMAN HALL: Were there any changes then

1 or what were the minor modifications that were made
2 between the Colorado Springs and the USAir accidents?

3 THE WITNESS: Flight 585 was a dash 200, I
4 believe, and this airplane is a dash 300. If there was
5 a change, it would have been in the yaw damper
6 authority; 2 versus 3 degrees or some change like that,
7 if there was a change.

8 CHAIRMAN HALL: Galling, I gather, is related
9 primarily to wear. Is that correct?

10 THE WITNESS: Well, my definition of wear is
11 you rub the two pieces together and they both
12 disappear. Galling would be where they tend to stick
13 together.

14 CHAIRMAN HALL: And referring to Exhibit 9-M,
15 which is a letter from the FM to then Chairman of the
16 National Transportation Safety Board on August 5th of
17 1993, which is pages 17 and 18, and I'll read it. It
18 says, "Since the issuance of this NPRM rulemaking, the
19 FM -- it's late.

20 "Since the issuance of this NPRM, the FM has
21 reevaluated the design of the rudder control system on
22 the model 727 and 737 series airplanes and has

1 determined that the flight crew would be capable of
2 detecting the galling condition by (1) increased forced
3 necessary to move the rudder peddle; (2) erratic nose
4 gear steering with the yaw damper engaged; (3) rudder
5 yaw damper kickback or yaw damper backdrives on the
6 rudder peddles during flight; and (4) erratic
7 operations of the rudder yaw damper or erratic rudder
8 oscillations with the yaw damper engaged. None of
9 these indications of galling represents a safety
10 hazard."

11 Number one, do you agree with the statement
12 that flight crews would be able to detect galling by
13 those four methods; and secondly, do you agree that
14 none of those indications of galling represent a safety
15 hazard?

16 THE WITNESS: We had at least one case where
17 the nut backed off. And when the nut backed off, the
18 package performed quite some time. We think it was
19 about two years in a perfectly normal fashion and would
20 have continued to operate until the seal wore out and
21 started to leak hydraulic fluid.

22 So if you were to say is this 100 percent

1 detectable by these four methods? There's at least one
2 case where, no, it just unscrewed and cured itself
3 operationally and continued on down the road. Whether
4 if you go on and say these phenomenon that are
5 described here, are they extreme safety issues? The
6 answer is the magnitude of all of these phenomenon are
7 readily controlled by the flight crew and that's the
8 basis for the statement.

9 CHAIRMAN HALL: Do you know based on this --
10 and I guess I'll have to ask somebody probably with the
11 FM -- what was done in terms of notifying the airlines
12 and flight crew so that they would know to be able to
13 detect galling?

14 THE WITNESS: I can't answer that.

15 CHAIRMAN HALL: Okay. I've been very
16 impressed with the amount of time that everyone has put
17 into both this accident and the Colorado Springs
18 accident. Was any additional failure analysis done in
19 terms of the rudder system between those two accidents
20 and did you come up with anything that you all felt
21 needed to be done as a result of that Colorado Springs
22 accident to that rudder?

1 THE WITNESS: I guess in answer to that is
2 that we continuously look at and monitor the system for
3 failures, look at things that are potential
4 improvements. And no, we did not come up with specific
5 changes that we wanted to do to the rudder system as a
6 result of 585.

7 CHAIRMAN HALL: But you mentioned you may be
8 coming up, as a result of this situation, with a
9 recommendation. You're not exactly sure what that
10 might be. Is there any type of time frame?

11 I know there's other work to be continued as
12 part of this investigation. Do you feel like that
13 there is anything additional that you need to do, any
14 other tests, failure analysis or any other technical
15 things that need to be done in this regard?

16 THE WITNESS: Not in the areas that I'm
17 responsible for, no.

18 CHAIRMAN HALL: Very well. Again, let me
19 thank you for the -- I think you've been up here over
20 two hours. You have been very responsive and I
21 appreciate it very, very much, as I'm sure the rest of
22 the panel does.

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1 SHIH YUNG SHENG, RUDDER PCU DESIGN ENGINEER, PARKER
2 HANNIFIN CORPORATION, IRVINE, CALIFORNIA

3

4 (Whereupon,

5

SHIH YUNG SHENG,

6

was called as a witness by and on behalf of the NTSB,

7

and, after having been duly sworn, wa examined and

8

testified on his oath as follows:)

9

CHAIRMAN HALL: Mr. Schleede, if you would

10

begin the questioning.

11

MR. SCHLEEDE: Give us your full name, Mr.

12

Sheng?

13

THE WITNESS: Yung Sheng.

14

CHAIRMAN HALL: Would you please say that

15

again, sir. I'm sorry. The microphone was not on.

16

THE WITNESS: My name is Yung Sheng.

17

MR. SCHLEEDE: Would you give us a brief

18

description of your background that qualifies you for

19

your position at Parker Hannifin?

20

THE WITNESS: I'm working for Parker Hannifin

21

with the Control System Division. My background, I

22

have a master of mechanical engineering degree from UC-

1 Berkeley.

2 MR. SCHLEEDE: How long have you worked for
3 Parker Hannifin?

4 THE WITNESS: Thirty-one years.

5 MR. SCHLEEDE: Thank you. Mr. Phillips will
6 proceed.

7 MR. PHILLIPS: Mr. Sheng, I appreciate your
8 sticking with us here.

9 Just a few questions. First of all, I guess
10 in our introduction we call you a Rudder PCU Design
11 Engineer. That's probably not quite accurate. What do
12 you do for Parker in your day-to-day business?

13 THE WITNESS: When I started as a young
14 engineer, I joined design teams working on all
15 different PCU designs, but currently my position is
16 senior member of Technical Staff. I provide all
17 technical support to different projects within our
18 division.

19 MR. PHILLIPS: So you act as an advisor to
20 other engineering groups within Parker on several
21 different actuator packages?

22 THE WITNESS: Yes. I just help them.

1 MR. PHILLIPS: Just help them out.

2 You're aware -- I guess you should ask, does
3 Parker manufacture the main rudder power control unit
4 for the 737 aircraft?

5 THE WITNESS: Yes.

6 MR. PHILLIPS: What other units do they
7 manufacture for the 737?

8 THE WITNESS: The aileron and the elevator
9 control units.

10 MR. PHILLIPS: Aileron and elevator control
11 units. Okay.

12 Parker also manufactures actuators and
13 components for several other aircraft that you've
14 worked on. Could you just give me a brief summary of
15 the other kinds of packages you work on and the
16 aircraft that they're used on?

17 THE WITNESS: Quite a few. First, 707
18 rudder, then some '27 rudders and elevators, and 747
19 inboard elevator, outboard elevator. On the SP, 747-
20 SP, in addition to the elevator, the rudders also.
21 Then on the 747-400, the inboard elevator, outboard
22 elevator, both rudders with the control model.

1 That is the Boeing hardware.

2 MR. PHILLIPS: Okay.

3 THE WITNESS: You want another list?

4 MR. PHILLIPS: Well, we don't really need the
5 list of each component, but what other aircraft
6 manufacturers do you make components for?

7 THE WITNESS: The aircraft?

8 MR. PHILLIPS: Just the company, not the
9 manufacturers. Not the particular airplanes, but the -
10 -

11 THE WITNESS: DC-10, the whole controls; in
12 the 11, the stabilizer. The Gulf Stream-2, all the
13 controls. Quite a few.

14 Now, military parts, we have C-5's, all
15 controls. S-38, all controls. Helicopters, like the
16 Black Hawk, all controls; Apache, all controls. It's a
17 long list.

18 MR. PHILLIPS: Yes. That's obvious.

19 In some reporting concerning this accident,
20 the USAir 427 accident, there was some reporting of a
21 c-141, I believe, actuator package. And the reference
22 was made that that was a Parker unit.

1 To your knowledge, does Parker manufacture a
2 rudder power control unit for the C-141 airplane?

3 THE WITNESS: It's not my knowledge, but I
4 don't know which one you're talking about. c-130.

5 MR. PHILLIPS: You make a C-130 package?

6 THE WITNESS: No. I'm sorry. This is the
7 recent accident?

8 MR. PHILLIPS: No. This was a report in the
9 media concerning a rudder package that Parker --
10 supposedly Parker manufactured that was installed in
11 the C-141.

12 THE WITNESS: I don't have the knowledge of
13 that.

14 MR. PHILLIPS: From your initial testimony,
15 it's obvious that Parker makes a lot of components.
16 How do they make a component? What starts a component
17 being made a Parker?

18 THE WITNESS: Okay. When customer need a new
19 PCU, they create what we call specification. Some of
20 the customers call procurement specification and we
21 call spec. Then we prepare a proposal design and
22 propose to the customer.

1 Normally it's open bid. And sometimes our
2 customer just give us the job. But anyway, after we
3 receive the job and create a design, we will meet the
4 customer specification requirements.

5 MR. PHILLIPS: And in this specification
6 requirement, what kinds of things are you given to work
7 with? Are you given drawings to manufacture the parts?
8 Are you given just design criteria that you try to meet
9 at the end?

10 THE WITNESS: Commercial designs, normally we
11 receive a schematic already that tells you how the
12 system looks like. And they give you an envelope to
13 tell you how much space they've got. And they give us
14 bench guidelines and requirements, so you design and
15 calculate to these requirements.

16 MR. PHILLIPS: When you meet the
17 requirements, you create a designed for specification,
18 does Parker have control of the engineering that
19 defines the components being manufactured? In other
20 words, is it Parker's decision that certain components
21 are used, certain materials are used? Exactly how does
22 that happen?

1 THE WITNESS: The specification defines the
2 performance and certain material restrictions. We have
3 some variation we can take to try to meet the
4 performance requirement.

5 MR. PHILLIPS: Do the manufacturers who
6 generate the specification to Parker, do they
7 participate in the design of the package if there are
8 specification changes?

9 THE WITNESS: They will design review our
10 design and normally there's a PDR, we call primary
11 design review. Then follows a CDR, critical design
12 review. So the customer has to approve our design.
13 Some of the customers even approve our detailed design.

14 MR. PHILLIPS: I see. Once the package is
15 designed and approved and goes into service with the
16 airlines, what's Parker's interaction then with both
17 the manufacturer and the airlines?

18 THE WITNESS: That part I'm not too familiar
19 with it. I'm in the design section. This would be in
20 the service section.

21 MR. PHILLIPS: I see. So you're more
22 involved with the specific design of the new

1 specification and a package before it goes into
2 service?

3 THE WITNESS: Yes.

4 MR. PHILLIPS: Have you been involved with
5 the Colorado Springs investigation or the Pittsburgh
6 accident investigation?

7 THE WITNESS: One day when Mr. Steve Weik was
8 not available, so they call me to support the
9 investigation. So I was there.

10 MR. PHILLIPS: That was the day everyone got
11 sick?

12 THE WITNESS: Yes.

13 MR. PHILLIPS: I guess we don't need to go
14 into that. So you came in as an advisor to Mr. Weik --

15 THE WITNESS: That's right.

16 MR. PHILLIPS: -- because he was out sick
17 that day?

18 THE WITNESS: Yes.

19 MR. PHILLIPS: What's been your involvement
20 over the years at Parker in the design of the 737 main
21 rudder PCU?

22 THE WITNESS: The 737 design, I just work on

1 the linkage, you know, all the linkage designs were
2 made by me.

3 MR. PHILLIPS: And the linkages are the --
4 could you tell us what they are?

5 THE WITNESS: All the moving parts.

6 MR. PHILLIPS: All the moving parts?

7 THE WITNESS: All the moving linkages you saw
8 on Bernie's presentation.

9 MR. PHILLIPS: Okay. Should we throw the
10 viewgraph up just to show what we're talking about? I
11 see a motion that way. I think one more flip -- and
12 one more. There we go.

13 THE WITNESS: Within this picture, only the
14 main control valve and the ball piston and the main
15 piston. That all belongs to the linkage. The rest of
16 the unit in the picture -- the rest of it belongs to
17 the linkage system and that was designed by me.

18 MR. PHILLIPS: So we're looking at some of
19 your original design there?

20 THE WITNESS: Yes.

21 MR. PHILLIPS: Have any of those parts ever
22 been used on another component manufactured by Parker?

1 THE WITNESS: No.

2 MR. PHILLIPS: They were unique to this unit,
3 this package?

4 THE WITNESS: Yes. You're right.

5 MR. PHILLIPS: When you design linkages and
6 components like that, what kind of criteria do you use
7 for knowing how to design them?

8 THE WITNESS: For linkage design, first you
9 have to know the input geometry and also you have to
10 know the output geometry. How much the pilot input to
11 give how much the actual output. You have to know that
12 geometry.

13 Then you have to know the autodynamics, so
14 you design the linkage to provide the velocity output
15 of the actuator, which meets the dynamic requirements.
16 It involves quite a bit of linkage designs; geometry,
17 motion, through the whole range. It's very
18 complicated.

19 MR. PHILLIPS: Yes. And are you involved in
20 selecting the materials for the linkages?

21 THE WITNESS: Yes.

22 MR. PHILLIPS: The testing that's done after

1 the design is complete to assure that the materials
2 meet those specifications, do you control that testing?
3 Are you involved in that?

4 THE WITNESS: We call qualification test. I
5 help our qualification department to run the test.

6 MR. PHILLIPS: So the unit is manufactured
7 and then it's tested to a test for performance. In
8 that process, is the manufacturer still involved in
9 identifying and developing the qualification test plan
10 or procedures?

11 THE WITNESS: Yes.

12 MR. PHILLIPS: Would you be prepared or is it
13 in your experience to talk about the effects of
14 contamination or particles getting into control valves?

15 THE WITNESS: I'm not an expert in that area,
16 but we have a filter in front of the inlet. So
17 normally the fluid is pretty clean when we reach the
18 components.

19 MR. PHILLIPS: In the service department or
20 the support of the PCU as it's in service with the
21 airlines, although it's not your area, are there ways
22 that information that comes back from the airlines can

1 get back to you so that you know when your design needs
2 to be modified or if it needs to be improved?

3 THE WITNESS: Normally, they were not sent to
4 me. Unless I request them, they will give it to me.

5 MR. PHILLIPS: If you requested it, they
6 would give it to you?

7 THE WITNESS: Oh, yes.

8 MR. PHILLIPS: Otherwise it's in other
9 people's hands to review?

10 THE WITNESS: That's right.

11 MR. PHILLIPS: In your opinion, is this main
12 rudder power control unit used on the 737, is it a
13 unique design? Is it different than any other design
14 out there?

15 THE WITNESS: The actual design principle,
16 basically is very common to all actuator designs. The
17 principle is very common. It's just like your car's
18 power steering. The power steering has a sole valve, a
19 linkage, just like that.

20 So the application for this particular unit
21 to just fit the 737.

22 MR. PHILLIPS: Has a unit like this been used

1 on any other airplane after the 737?

2 THE WITNESS: Not this particular unit.

3 MR. PHILLIPS: Not this particular unit.

4 My advisors here are asking me to ask you to
5 maybe discuss a little bit the function of the dual
6 spools in the servo control valve. Could you just
7 generally give us an overview of in a control valve why
8 we have dual concentric spools?

9 THE WITNESS: Because the design requirement,
10 as I remember, it says there's no one single failure.
11 It endangers the rudder system. So Mr. Turner already
12 explained to you if the primary jams or the secondary,
13 then the secondary can reverse the direction and will
14 solve the actuator.

15 MR. PHILLIPS: Is this dual concentric
16 control valve used on other Parker PCU's?

17 THE WITNESS: Yes.

18 MR. PHILLIPS: And which ones are those?

19 THE WITNESS: The first one is 727 elevator.
20 Then it's 707 rudder, then 737 rudder. That's this
21 one. The next one is the 747 inboard elevator.

22 As I remember the 737 A and E, the aileron

1 and elevator unit also got the dual concentric valve.

2 MR. PHILLIPS: After the Colorado Springs
3 accident investigation the NTSB wrote a safety
4 recommendation asking the FM to review and Boeing to
5 review dual concentric servo valve designs manufactured
6 by Parker in regards to failure conditions.

7 Were you involved in that review or were you
8 aware that that recommendation had been made and a
9 review was being conducted?

10 THE WITNESS: I studied the design and helped
11 to modify the design. But as far as the whole review,
12 I participated in that.

13 MR. PHILLIPS: You did participate in that?

14 THE WITNESS: Yes.

15 MR. PHILLIPS: And you also were involved in
16 modifying the design of the 737 PCU after the Colorado
17 Springs event?

18 THE WITNESS: Yes. That's correct.

19 MR. PHILLIPS: In the original -- in the list
20 that you just gave me of other dual concentric valves
21 manufactured by Parker, are there any significant
22 differences in specifications or tolerances, clearances

1 and things in those valves or are they all generally
2 the same?

3 THE WITNESS: Generally, they're all same.

4 MR. PHILLIPS: Do you have anything else
5 you'd like to add, any other area that I haven't
6 covered you'd like to discuss?

7 THE WITNESS: No.

8 MR. PHILLIPS: Thank you very much. I have
9 no further questions.

10 CHAIRMAN HALL: Do the parties have questions
11 of this witness?

12 (No response.)

13 I see no hands.

14 Mr. Marx?

15 MR. MARX: I just have a few quick questions.

16 The linkage that you design on the 737, is
17 that a redundant linkage or each one of those --

18 THE WITNESS: Yes.

19 MR. MARX: -- links themselves, if one breaks
20 -- I mean, would you just explain the design?

21 THE WITNESS: They're all redundant. They
22 all have dual load paths.

1 MR. MARX: So each one of the individual
2 components have a dual or like two components in one.
3 Is that correct?

4 THE WITNESS: Yes. Okay. The first piece is
5 the external summing lever. It's actually got four
6 pieces bound together. The external summing lever. In
7 the picture you don't see the actual four pieces bound
8 together. In the next one you have the link. You have
9 two pieces bond against each other. They're riveted
10 together.

11 MR. MARX: And each one of those individual
12 pieces that are bonded together can carry the full load
13 of the link?

14 THE WITNESS: Yes. That's right. And the
15 shaft, actually you've got two shafts, one inside each
16 other -- one inside the other.

17 MR. MARX: In the linkage itself, is this all
18 an open air or to the ambient environment?

19 THE WITNESS: External linkage; yes.

20 MR. MARX: And what about the internal
21 linkage?

22 THE WITNESS: It's in the linkage cavity,

1 which is the return fluid.

2 MR. MARX: Okay. The linkage cavity would be
3 that which would have the summing levers in them?

4 THE WITNESS: The internal summing levers.

5 MR. MARX: Is there any place in that linkage
6 that can cause or can be a source of binding or
7 sticking in the linkage itself that can cause some type
8 of jam?

9 THE WITNESS: I'm not aware of that.

10 MR. MARX: Is there any place in the linkage
11 that it comes close to other components in which
12 something could get stuck in between that and another
13 spot and cause a jam?

14 THE WITNESS: Since the linkage cavity is
15 isolated, the foreign particle would not get into that,
16 so there's no foreign object that will cause the
17 jamming.

18 MR. MARX: Okay. I have no further
19 questions.

20 CHAIRMAN HALL: Mr. Clark?

21 MR. CLARK: You described a number of
22 packages that Parker designs that go on various

1 airplanes and I lost track. Do you build the packages
2 that are used on the rudder systems on the 727?

3 THE WITNESS: Yes.

4 MR. CLARK: So there's two systems for each
5 airplane in that design?

6 THE WITNESS: Two rudders. One upper rudder;
7 one lower rudder.

8 MR. CLARK: Is that rudder system similar to
9 the rudder system on the 737?

10 THE WITNESS: No.

11 MR. CLARK: It's not a derivative or the body
12 of the actuator the same part number or a similar part
13 number?

14 THE WITNESS: The valve is completely
15 different.

16 MR. CLARK: The valve is the servo valve?

17 THE WITNESS: The main control valve.

18 MR. CLARK: The main control valve is
19 completely different.

20 THE WITNESS: Completely different. It's a
21 single slide. It's not a valve in a valve.

22 MR. CLARK: Is the actuator itself, the

1 piston, are they similar or -- similar in design
2 although they may be different in size or there may be
3 differences that create a different part number?

4 THE WITNESS: It's a completely different
5 part number. None of them can interchange.

6 MR. CLARK: If you suspected a design
7 problem, for example, in the 737 package, would that
8 lead you to look for similarities in the 727 package
9 then?

10 THE WITNESS: You're talking the 727 rudder?

11 MR. CLARK: Yes.

12 THE WITNESS: I'm not aware of any problem on
13 that.

14 MR. CLARK: If you found -- I guess I'm
15 asking for the similarities of design and you're
16 indicating they are quite dissimilar.

17 THE WITNESS: Not same.

18 MR. CLARK: Okay. Not the same at all.
19 Okay. Thank you.

20 THE WITNESS: Not similar.

21 MR. CLARK: You also said that the dual
22 concentric valve is used on several different designs.

1 Are all of those dual concentric valves a derivative of
2 the one that is on the 737 or are they similar or
3 similar part numbers?

4 THE WITNESS: The principle's the same.

5 MR. CLARK: The principle's the same but
6 they're different designs?

7 THE WITNESS: The design is different.

8 MR. CLARK: Every one of those others are
9 completely different then?

10 THE WITNESS: The 737 and 727 a little close,
11 but still not same.

12 MR. CLARK: It's hard to quantify what is a
13 little close. Does the external package of the valve
14 look the same or does it start with the same -- similar
15 parts and give them different part numbers for slight
16 differences in size?

17 THE WITNESS: The main difference in the 727
18 there is no external linkage stop because there is no
19 yaw damper on that.

20 MR. CLARK: Do you incorporate the summing
21 lever design -- well, that goes back to the rudder
22 package itself. Is that summing lever design used on

1 other packages other than the 737?

2 THE WITNESS: I didn't follow your question.

3 MR. CLARK: You design the summing levers on
4 the 737 rudder package?

5 THE WITNESS: Yes.

6 MR. CLARK: Are those summing levers used on
7 other --

8 THE WITNESS: No.

9 MR. CLARK: Completely different?

10 THE WITNESS: Completely different.

11 MR. CLARK: Now, back to the concentric
12 valve. For the 737 design in the rudder package, a
13 similar design is used on the 727 for what part? The
14 elevator?

15 THE WITNESS: The elevator. Yes.

16 MR. CLARK: Are you aware of any failure
17 modes or failures or malfunctioning servo valves on the
18 737 rudder package?

19 THE WITNESS: Yes.

20 MR. CLARK: Would you describe those?

21 THE WITNESS: One unit in the extreme extreme
22 worst condition, the pressure can reverse.

1 MR. CLARK: Okay. That's a -- is that from
2 the MacMore unit? That design?

3 THE WITNESS: Yes.

4 MR. CLARK: And that's the only type of
5 design -- that's the only unit you're aware of in the -
6 -

7 THE WITNESS: That's the only unit I'm aware
8 of.

9 MR. CLARK: And that was one that became
10 apparent in the investigation of the Colorado Springs
11 accident or an outgrowth of that?

12 THE WITNESS: During the investigation. Yes.

13 MR. CLARK: For the other dual concentric
14 valves that are used on those other airplanes, are you
15 aware of any types of failures that have occurred on
16 those valves?

17 THE WITNESS: I don't have the knowledge.

18 MR. CLARK: You would not be the person to
19 ask for that?

20 THE WITNESS: Right.

21 MR. CLARK: Okay. I have no further
22 questions.

1 CHAIRMAN HALL: Mr. Schleede?

2 MR. SCHLEEDE: Okay. Sir, are you aware if
3 there's any testing done during initial design phase
4 and certification for the PCU unit, including the servo
5 valve, for chip shear? Jamming of the servo valve from
6 chips?

7 THE WITNESS: I don't have the knowledge.

8 MR. SCHLEEDE: You're not aware of that?

9 THE WITNESS: I don't know. Maybe there is,
10 but in those days I was not involved in the valve area,
11 so I don't have any idea if they did or not.

12 MR. SCHLEEDE: Was there any other testing
13 for mechanical failures in any of the other linkages,
14 full scale testing for jams?

15 THE WITNESS: We test to the specs limit
16 load.

17 MR. SCHLEEDE: Are you aware of any -- you
18 may have answered this question -- of any malfunctions
19 or jams or conditions of that type in the summing
20 levers, in the linkages of the PCU that could cause a
21 runaway rudder?

22 THE WITNESS: Not on the 737.

1 MR. SCHLEEDE: You're not aware of any
2 occurrences?

3 THE WITNESS: Not aware. Even we tried to
4 find some, but no.

5 MR. SCHLEEDE: Okay. Are you a designated
6 engineering representative for the FM

7 THE WITNESS: No.

8 MR. SCHLEEDE: Do service difficulties that
9 are reported with these products that you work on, are
10 they reported to you?

11 THE WITNESS: No. They report to the
12 projects.

13 MR. SCHLEEDE: To which office?

14 THE WITNESS: To the project.

15 MR. SCHLEEDE: Project engineers?

16 THE WITNESS: Yes.

17 MR. SCHLEEDE: That's all I have. Thank you.

18 CHAIRMAN HALL: Mr. Sheng, you designed this.
19 You're the original designer, correct, of the power --

20 THE WITNESS: Just the linkage.

21 CHAIRMAN HALL: Of the linkage. Okay.

22 And I may be getting -- I may need to address

1 CHAIRMAN HALL: This hearing will reconvene
2 at 8:30 a.m. in the morning to begin with the testimony
3 of Mr. Paul Cline.

4 (Whereupon, the proceedings were adjourned at
5 6:02 p.m., to be reconvened at 8:30 a.m. on Wednesday,
6 January 25, 1995 in the same place.)

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